

**Volume IV of IX (Appx40093-Appx53151)**  
**No. 2024-1285**

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**UNITED STATES COURT OF APPEALS**  
**FOR THE FEDERAL CIRCUIT**

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APPLE INC.,

*Appellant,*

v.

INTERNATIONAL TRADE COMMISSION,

*Appellee,*

MASIMO CORPORATION, CERCACOR LABORATORIES, INC.,

*Intervenors,*

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On Appeal from the United States International Trade Commission  
in Investigation No. 337-TA-1276

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**NON-CONFIDENTIAL JOINT APPENDIX**

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Appx70956

### **ADDITIONAL DOCUMENTS**

USPTO Order Denying *Ex Parte* Reexamination for U.S. Patent Appx70957-  
10,912,502, May 30, 2024 Appx71010

USPTO Order Denying *Ex Parte* Reexamination for U.S. Patent Appx71011-  
10,945,648, May 30, 2024 Appx71035

Respondent Apple Inc.'s Emergency Motion to Suspend Any Appx71036-  
Remedy or Extend the Target Date and Stay Proceedings Pending Appx71222  
Resolution of Any appeal of the Patent Office's Decision that  
United States Patent Nos. 10,638,941, 10, 595,731 and 9,572,499  
Are Unpatentable (ITC Inv. No. 337-TA-1266)

CX-0635C-MASITC 01076914 - Appendix B - Masimo Watch Appx71223-  
R&D Expenditures, LTD Labor **[SEALED]** Appx71227

CX-0635C-MASITC-01076914 - Appendix B - Masimo Watch Appx71228-  
R&D Expenditures, R&D Summary **[SEALED]** Appx71231

CX-0624C-MASITC-01076803 – Appendix C - Watch Corporate Appx71232-  
Expenditures, v1, v2, v3 **[SEALED]** Appx71233

CX-0632C-MASITC-01076911 - Appendix F - Watch Sourcing Appx71234-  
IT and Recruiting Expenditures, Summary **[SEALED]** Appx71235

CX-0450C-MASITC-01076919 - Appendix M - Masimo Wrist Worn R&D Expenditures, Summary **[SEALED]** Appx71236-Appx71240

CX-0648C-MASITC-01076927 - Appendix S - Watch Headcount, v1 **[SEALED]** Appx71241-Appx71244

Mickle, Tripp, *Apple Keeps Losing Patent Cases. Its Solution: Rewrite the Rules*, N.Y. Times (Mar. 19, 2024) Appx71245-Appx71250

CERTIFICATE OF SERVICE

**CONFIDENTIAL MATERIAL OMITTED**

The material omitted from Appx9; Appx36; Appx41-44; Appx46-48; Appx108; Appx119; Appx121-122; Appx150-151; Appx153-154; Appx156-158; Appx187-190; Appx192-194; Appx196; Appx198; Appx218; Appx220-222; Appx265-276; Appx373; Appx13067-13069; Appx21846; Appx22790; Appx22954; Appx22956-22958; Appx22985; Appx22990; Appx23139; Appx23166; Appx23171-23174; Appx23238; Appx23249; Appx23251-23252; Appx23280-23281; Appx23283-23284; Appx23286-23288; Appx23317-23320; Appx23322-Appx23323; Appx23326; Appx23328; Appx23348; Appx23350-23352; Appx23395-23406; Appx23656; Appx23658; Appx23681-23682; 23688; Appx23791; Appx24147-24148; Appx40795-40798; Appx40996-40999; Appx41019-41026; Appx41029-41030; Appx41058-41062; Appx41077-41080; Appx41094-41097; Appx41108-41110; Appx51900-51924; Appx52602-52606; Appx52609; Appx52642-52645; Appx52791-52795; Appx52822-52824; Appx52911-52912; Appx52939-52941; Appx52980-52982; Appx53016-53019; Appx60425-60431; Appx60432-60434; Appx70322-70355; Appx70774; Appx70781-70783; and Appx70841-70876 contains Apple's confidential competitively sensitive product information subject to the Administrative Protective Order; the material omitted from Appx4579 and Appx53459-53461 contains competitively sensitive information regarding confidential agreements; the material omitted from Appx23439; Appx23441-23446; Appx23448; Appx23450-23453; Appx23455-23458; Appx23462; Appx23617; Appx23621; Appx23659-23665; Appx25251; Appx40483; Appx40582-40584; Appx40600-40601; Appx40605; Appx40652-40655; Appx40658-40662; Appx53491; Appx53492; Appx53497; Appx53499; Appx53503; Appx53506; Appx65064-65075; Appx65075; Appx65104-65105; Appx65315; Appx65321-65232; and Appx71223-71244 contains Masimo's confidential competitively sensitive financial information subject to the Administrative Protective Order; the material omitted from Appx311-316; Appx23667-23674; Appx40579-40581; Appx40585-40599; Appx40602-40604; Appx40610-40614; and Appx40631-40633 contains Masimo's confidential competitively sensitive financial and manufacturing information subject to the Administrative Protective Order; the material omitted from Appx473-474; Appx62; and Appx23176-23178 contains Masimo's confidential competitively sensitive manufacturing information subject to the Administrative Protective Order; the material omitted from Appx13047; Appx14129-14140; Appx205-206; Appx211; Appx21848; Appx22282-22286; Appx23197; Appx23204; Appx23335-23336; Appx23341; Appx23408-23416; Appx23434-23436; Appx23454; Appx23642; Appx23644-23645; Appx23647-23649; Appx23685-23687; Appx23693-23697; Appx23704; Appx25253-25260; Appx278-286; Appx2809-

2852; Appx2923-2937; Appx304-306; Appx309; Appx3708; Appx3710-3711; Appx3718; Appx3722; Appx3725; Appx3727; Appx3732; Appx3733; Appx3735; Appx40229-40232; Appx40346-40371; Appx40407-40422; Appx40431-40434; Appx40438-40442; Appx40486-40494; Appx40495-40506; Appx40512-40521; Appx40525-40528; Appx40547-40555; Appx40560-40574; Appx40803-40822; Appx41217-41221; Appx41350-41356; Appx53070-53095; Appx53107-53151; Appx53222-53234; Appx53236-53252; Appx53256-53361; Appx53362-53365; Appx53813-53838; Appx53927-53941; Appx54064-54226; Appx54227-54266; Appx55229-55354; Appx55359-55376; Appx55386-55399; Appx57317-57324; Appx57394--57409; Appx57410-57412; Appx57615-57618; Appx60136-60153; Appx60184-60212; Appx65014-65019; Appx65022-65025; Appx65028-65037; Appx65040-65074; Appx65207; Appx65224; Appx65267-65268; Appx67; Appx6701-6703; Appx6705; Appx6732-6736; Appx6852-6854; Appx6937-6950; Appx70475; Appx70484-70491; Appx70504-70513; Appx70518-70559; Appx70610-70613; Appx70615-70617; Appx70619-70628; Appx70833-70835; Appx70948-70950; Appx70955-70956; and Appx74 contains Masimo's confidential competitively sensitive product information subject to the Administrative Protective Order; the material omitted from Appx23707-23709; Appx318; Appx320-328; Appx40634; and Appx70592-70594 contains Masimo's confidential competitively sensitive product and financial information subject to the Administrative Protective Order; the material omitted from Appx176; Appx179; Appx22788-22789; and Appx22791 contains Masimo's confidential information detailing non-public patent prosecution subject to the Administrative Protective Order; the material omitted from Appx404-405; Appx457; Appx460-461; Appx464; Appx24103-24104; Appx25387; and Appx25389 contains Apple's confidential competitively sensitive financial and sales information subject to the Administrative Protective Order; the material omitted from Appx52602-52608 contains confidential competitively sensitive product of a third party.

# UNITED STATES INTERNATIONAL TRADE COMMISSION

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In the Matter of

Investigation No.

CERTAIN LIGHT-BASED PHYSIOLOGICAL 337-TA-1276

MEASUREMENT DEVICES AND COMPONENTS

THEREOF

-----x

REVISED AND CORRECTED TRANSCRIPT

OPEN/CLOSED SESSIONS

Pages: 1 through 282

Place: Washington, D.C.

Date: June 6, 2022

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1 UNITED STATES INTERNATIONAL TRADE COMMISSION

2 Washington, D.C.

3 Before the Honorable Monica Bhattacharyya

4 Administrative Law Judge

5

6 -----x

7 In the Matter of Investigation No.

8

9 CERTAIN LIGHT-BASED PHYSIOLOGICAL 337-TA-1276

10 MEASUREMENT DEVICES AND COMPONENTS

11 THEREOF

12 -----x

13

14

15 EVIDENTIARY HEARING

16 Monday, June 6, 2022

17 Volume I

18

19

20 The parties met via remote videoconferencing  
21 pursuant to notice of the Administrative Law Judge at 9:30  
22 a.m. Eastern.

23

24

25 Reported by: Linda S. Kinkade RDR CRR RMR RPR CSR

1 A P P E A R A N C E S:

2 [All parties appeared via remote videoconferencing and/or  
3 telephonically.]

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24 \*\*\* Index appears at end of transcript \*\*\*

25

1 than argue about their admissibility in advance.

2 JUDGE BHATTACHARYYA: That's fine, if that's the  
3 procedure -- that's fine.

4 MR. RE: Yes. There are four objected to  
5 exhibits that I do want to introduce despite the objection,  
6 and I'm ready to respond if argument is required.

7 JUDGE BHATTACHARYYA: Okay.

8 MR. RE: Thank you.

9 JUDGE BHATTACHARYYA: Welcome, Mr. Kiani. Do you  
10 understand that you're under an obligation to tell the truth  
11 here today?

12 THE WITNESS: Yes, Your Honor.

13 JOSEPH KIANI,  
14 having been first duly sworn and/or affirmed  
15 on his oath, was thereafter examined and testified as  
16 follows:

17 DIRECT EXAMINATION

18 BY MR. RE:

19 Q. Good morning, Mr. Kiani. For the record, could  
20 you please give your full name and spell your name?

21 A. Yes. My name is Massi Joseph E. Kiani,  
22 M-A-S-S-I, Joseph, E, and K-I-A-N-I.

23 Q. What are your current positions?

24 A. I am chairman and CEO of Masimo and Cercacor.

25 Q. For how long have you been the CEO of Masimo?

1           A.    Since inception.   Since 1989 where I started  
2   Masimo in my garage.

3           Q.    Could you briefly tell us about your formal  
4   education?

5           A.    Yes.   I have my bachelor's and master's from San  
6   Diego State University in electrical engineering.

7           Q.    And the master's, what was your master's degree  
8   on at San Diego State?

9           A.    Advanced signal processing, adaptive filters, AI.

10          Q.    When you said you started Masimo in 1989, what  
11   was your main purpose in starting Masimo?

12          A.    I wanted to solve the motion artifact problem  
13   with pulse oximeter.

14          Q.    What exactly, briefly, is pulse oximetry?

15          A.    Pulse oximetry is the noninvasive measurement of  
16   arterial oxygen saturation and pulse rate using two  
17   wavelengths of light passing through a tissue and looking at  
18   the pulsatile information and normalizing that from the bulk  
19   or the DC information.

20          Q.    Now you mentioned this motion problem.   Explain  
21   to me what exactly is the motion problem.

22          A.    Well, the assumption pulse oximetry makes, the  
23   invention of pulse oximetry back in '72 with Dr. Aoyagi, is  
24   that whatever pulsates is what we're interested in.

25                   During motion the venous blood starts pulsating

1 at your frequency of motion. Venous blood is typically less  
2 than 10 millimeter mercury or your arterial is probably 100,  
3 120. So it's a Jell-O pool of blood.

4 So when you start moving, the venous information  
5 starts getting in the signal, and it confused a conventional  
6 pulse oximeter to give a normalized average of arterial and  
7 venous saturation.

8 Q. And in addition to motion, what other major  
9 problem did you learn about in tackling this motion problem?

10 A. Low perfusion. Low perfusion is when there's low  
11 blood flow to the extremity. When your hands are cold, you  
12 have low perfusion. I usually have cold hands, and that's  
13 why I noticed the problem early on as an engineer with the  
14 motion and low perfusion.

15 It's not just a low signal-to-noise problem.  
16 When you have low perfusion, because your hand typically is  
17 your radiator trying to keep you cool, when you have cold  
18 hands, you're not getting enough really -- you're not  
19 getting a lot of arterial blood supply.

20 So the venous saturation becomes really low, like  
21 50 percent, versus when you're hot, it could be 97.

22 So when you move, when you have low perfusion, it  
23 really shows the problem of motion with pulse oximetry.

24 Q. Mr. Kiani, you can stare at the camera. It looks  
25 like you're probably looking at a screen of me.

1 A. Yeah. I'm looking at you. Sorry.

2 Q. Look at the camera. That's much better.

3 And who else was part -- why was this motion  
4 problem significant in the hospitals?

5 A. Well, when the patients were first monitored for  
6 pulse oximetry it was in the operating room where patients  
7 are sedated and not moving, but when patients started going  
8 outside the OR and being monitored in the ICU, intensive  
9 care unit, or neonatal unit, or recovery room, they don't  
10 stay still.

11 So when they began moving, they realized 70 to 90  
12 percent of the alarms were false alarms due to motion  
13 artifact and low perfusion.

14 Q. And what other were some of the effects of these  
15 caused by motion problems in patients?

16 A. Well, crying wolf made clinicians ignore the  
17 alarm. They were finding a lot of patients dead in bed,  
18 literally, because they ignored the alarm.

19 And the neonatal intensive care unit where you're  
20 not just worried about too little oxygen, but you're worried  
21 about too much oxygen, because the baby's eyes aren't  
22 developed yet, a lot of babies were getting severe eye  
23 damage. Two thousand a year were becoming blind. In fact,  
24 Stevie Wonder is blind from ROP, retinopathy of prematurity,  
25 in the neonatal ICU.



1 Q. Can you say that word, ROP, more slowly for the  
2 court reporter? What does it stand for?

3 A. Sure. Retinopathy of prematurity, so eye damage  
4 due to prematurity, but it's really due to gyrations in the  
5 oxygen in the neonatal ICU because they didn't have a  
6 trustworthy pulse oximeter.

7 Q. And who joined you in this endeavor to begin  
8 tackling the motion and low perfusion problems?

9 A. Mohamed Diab. Six months after I started Masimo,  
10 Mohamed joined me, and he -- I started Masimo with a \$40,000  
11 loan on my condo, and I wanted Mohamed to join, but he said  
12 until you raise money from third parties, I'm not sure I'm  
13 going to give up my job to join you, because I had raised by  
14 then \$80,000 from other people, and Mohamed joined me.

15 Q. What did Mr. Diab do when he joined Masimo?

16 A. He developed the circuit and wrote the software.  
17 Eventually he became our chief technical officer.

18 Q. And what techniques did you begin to use to  
19 tackle this motion problem with pulse oximetry?

20 A. Well, I had studied, my master's work, area of  
21 adaptive filters, which had been used in antisubmarine  
22 warfare and satellite communication, and adaptive filters  
23 were incredibly a useful tool because they could adapt to  
24 the noise.

25 So when they saw noise coming at a certain

1 frequency versus another frequency, it would adapt its  
2 coefficients to cancel. Because the problem -- canceled the  
3 noise frequency. The problem is motion is happening in the  
4 same window that we're looking for a signal, which is from  
5 30 beats per minute to 300 beats per minute.

6 So adaptive filters, which I thought would work,  
7 ended up working along with things we call parallel engines  
8 and improved sensor design and hardware design to actually  
9 get rid of the motion artifact problem and the low perfusion  
10 problem.

11 Q. I'd like to delve in quickly to some of your  
12 early products. If you could -- there's a book in there --  
13 you can look at the book if you need to see the original.

14 We'll put it on the screen to try to save some  
15 time, but, in particular, I'd like to direct your attention  
16 to Complainants' or CX Exhibit 1370. If you can just tell  
17 me what that is.

18 A. That is our 25th year anniversary annual report  
19 from our incorporation.

20 Q. And I'd like to take you to page 4 of that  
21 report, which begins a multipage timeline.

22 Do you see that?

23 A. I do.

24 Q. I wonder if you could briefly describe some of  
25 your early products that are represented by this timeline.

1           A.    Yes.  So after our founding in '89, we show here  
2    in 1995, for the first time we showed Masimo pulse oximetry  
3    at the Society of Technology and Anesthesia and introduced  
4    an OEM board called the MS-1 that we wanted companies that  
5    made patient monitors to incorporate to have Masimo SET  
6    level pulse oximetry.

7           Q.    And how were your products initially received  
8    bought these boards?

9           A.    Well, everyone was blown away at what we could  
10   do.  The industry had tried for years to deal with the  
11   motion artifact problem and had concluded that it was  
12   impossible to solve.  It was just inherent limitation of  
13   pulse oximetry.

14                So when we showed people we could actually  
15   measure-through-motion and low perfusion, everyone was just  
16   blown away, and it was highly regarded.

17          Q.    And then after 1995 I see some entries for  
18   some -- your own products.

19                Do you see those?  In 1998, '96, do you see  
20   those?

21          A.    Yes.

22          Q.    What did you begin to do with your boards after  
23   you introduced the MS1?

24          A.    Well, first of all, by 1996 is when the first  
25   time the product shipped to consumers, when this case being

1 the clinical consumers, and through an OEM we called Contron  
2 from England, but you see the LNOP sensor, which is our low  
3 noise optical probe sensor that was introduced then, later  
4 we created our own standalone device with the help of a  
5 company called Ivy Biomedical where we could show standalone  
6 pulse oximeter with our technology rather than a  
7 multiparameter patient monitor. And then NEC created the  
8 standalone as well.

9 Q. I'd like you to take a look at what is page 35 of  
10 this annual report, particularly the right side.

11 If you could briefly explain, what is this chart  
12 shown in your annual report?

13 A. Well, by now numerous clinical studies had come  
14 out showing the advantages of Masimo SET. This was the most  
15 comprehensive done by Dr. Steven Barker. I think it was in  
16 2002 that this came out.

17 And he compared Masimo SET to all of the  
18 available commercial pulse oximeters at the time. And he  
19 looked at their sensitivity versus their specificity, and  
20 this is what is known as a ROC curve, a receiver operating  
21 characteristic curve, which plots on the y-axis the  
22 sensitivity, on the x-axis one minus the specificity. An  
23 ideal product should go straight up. You can see we're  
24 pretty close to that. That red is Masimo SET.

25 For example, at a 95 percent sensitivity, we have

1 about a 3 percent false alarm rate, where, if you just keep  
2 going right, they get a lot worse, 30, 40, 50 percent false  
3 alarm, and some of them are worse than the flip of a coin.  
4 These are random number generators.

5 Q. For the record, I need you to define what's the  
6 difference between the sensitivity of a device and the  
7 specificity of a device.

8 A. Yes. Sensitivity is the ability to pick up true  
9 alarm, a true event. Specificity is the ability to reject  
10 false events. So you would like to have a product that's  
11 100 percent sensitive and 100 percent specific.

12 Q. I'd like you to take a look at what has been  
13 marked as Complainants' Exhibit 0777.

14 If you could just identify this document for the  
15 record.

16 A. Yes. This is what we referred to as  
17 bibliography. It summarizes some of the studies on SET,  
18 Masimo SET pulse oximetry, and rainbow« pulse, which is this  
19 multiwavelength blood constituent sensor that you put on  
20 your site to measure 12 parameters.

21 Q. And tell me how many articles and studies have  
22 confirmed the superiority of Masimo SET technology?

23 A. Over a hundred. Over a hundred. And what's  
24 really unique here is in clinical world usually, whatever  
25 you create, a third of the studies say they're better, a

1 third say they're worse, a third is neutral. In our case,  
2 over a hundred said it was positive and a couple neutral.

3 Q. Now you mentioned the LNOP, the low noise optical  
4 probe.

5 If we can go back to that, 1370, page 4, and blow  
6 up that 1996 entry.

7 A. Yes.

8 Q. Is this -- tell me more about this sensor. Is  
9 this a single patient use? What kind of sensor are we  
10 talking about here.

11 A. If you zoom out of the picture --

12 Q. 1996.

13 A. Go back to 1996 LNOP, if you go look at that,  
14 just go -- so what you see is it's an adhesive, single  
15 patient use sensor, and that white bump you see there,  
16 that's actually the invention there. That's a cavity that  
17 the digit can sit on to minimize the impact of motion.

18 Q. How did you market this as assisting with your  
19 Masimo SET performance?

20 A. Well, it was part of the system. We were trying  
21 to solve this problem of motion artifact, as I mentioned,  
22 and what we figured out that, if you put the soft tissue  
23 into this cavity, you minimize the optical perturbation of  
24 the site.

25 Q. And so it's the subject of a patent, I

1 understand?

2 A. Yes. In fact, the name of the sensor is the  
3 title of the patent, low noise optical probe.

4 Q. For the record, it's Complainants' Exhibit 1586.  
5 If we can call that up.

6 Is this the patent on that sensor?

7 A. Yes, it is.

8 Q. And if we can go to Fig. 4, I'd like you to  
9 describe for the record what's shown in Fig. 4 of this '818  
10 patent.

11 A. Yeah. Basically, the dashed lines is the body of  
12 the sensor, where you see the flesh, the 128 is sitting on,  
13 130 is the LED that's shining through the tissue going to  
14 the photodetector 126. And you see the photodetector is  
15 recessed, and it's actually in a cavity where the tissue can  
16 sit on underneath where you have these protective dashed  
17 line barriers to make sure you don't get light piping but  
18 you get the light from the LED to the photodetector.

19 Q. And 128, is that the finger or tissue?

20 A. Yes.

21 Q. Okay. And the detector is 126 in the bottom of  
22 the well, is that what you're saying?

23 A. Yes.

24 Q. Okay. And what did other sensors at that time  
25 do, which made this a patentable invention, in your mind?

1           A.     Well, everybody else in the industry would bring  
2     the detector right up to the 128, the patient finger in this  
3     case, and have -- try to be as planar and flat as they could  
4     with the sensors, the detector and the LED.

5           Q.     How did the medical device industry react to  
6     Masimo's entry into the pulse oximetry market?

7           MR. MUELLER:   I'll object for lack of foundation  
8     as to what other folks may have reacted to.   Mr. Kiani can  
9     talk about his own reactions, but I would object on lack of  
10    foundation grounds and hearsay grounds to the perspective of  
11    third parties.

12           JUDGE BHATTACHARYYA:   Mr. Re, did you want to  
13    respond?

14           MR. RE:   I'll rephrase.

15           Q.     What did you personally experience when you  
16    introduced your products in the medical device industry?

17           A.     Well, after our patent was published, everybody  
18    became all of a sudden quite smart.   What they couldn't do  
19    for over a decade before in solving the motion problem,  
20    everyone all of a sudden seemed to have a solution.

21           So several companies violated our patents.   We  
22    ended up suing Nellcor, which is the market leader, about 90  
23    percent market share at the time, and once we won that  
24    litigation, everybody else except for two, a Chinese company  
25    called Mindray and a European company called Philips, we had



1 to sue them. They wouldn't stop. And ultimately Mindray  
2 settled right before trial, and Phillips went to trial, and  
3 we won that litigation, both with the jury and the judge.

4 Q. I just want to go back to the Nellcor case.

5 What was the outcome of the Nellcor patent  
6 infringement case?

7 A. Yeah, the Nellcor case, the court ordered that  
8 040505 CI, which was the technology generations for Nellcor,  
9 had infringed our IP, and the Federal Circuit court ordered  
10 their injunction of those products.

11 MR. MUELLER: I'm sorry. I'm just going to move  
12 to strike testimony about court decisions from other cases  
13 involving patents not asserted in this case. I object and  
14 move to strike Mr. Kiani's testimony characterizing  
15 decisions from other bodies on a patent not in this suit.

16 JUDGE BHATTACHARYYA: Mr. Re?

17 MR. RE: The court can take judicial notice.  
18 This is all public information in court filings, at the  
19 Federal Circuit, in the Central District of California,  
20 everything Mr. Kiani mentioned is all of public record.

21 JUDGE BHATTACHARYYA: The objection is overruled  
22 as to weight, not admissibility.

23 Q. Does Masimo or you have an estimation of how many  
24 patients a year are monitored with Masimo technology?

25 A. Yeah, over 200 million patients are monitored

1 with Masimo pulse oximetry now.

2 Q. And as CEO of Masimo, can you tell me how your  
3 products made a difference in health care today?

4 A. Yes. Dramatic. We have helped reduce blindness  
5 in the neonatal ICUs. These are all documented by clinical  
6 studies, the outcome studies. We have helped save lives on  
7 postsurgical patients that were on opioids.

8 And recently, even with COVID, when patients  
9 couldn't be admitted to the hospital because there were too  
10 many patients in the hospital with COVID, they used our  
11 technology to send the COVID patients home, and a study had  
12 just come out showing 70 percent reduction in mortality.

13 No other pulse oximeter has ever shown outcome  
14 improvement except Masimo's.

15 Q. And has Masimo received awards for its technical  
16 achievements?

17 A. Yes. Numerous awards. Over 50 awards.

18 Q. In fact, if you can just, for the record, tell me  
19 what is Exhibit 1378, if we can call that up.

20 A. Yeah, this is some of the awards we've received  
21 for our inventions, the latest one being FDA granting us,  
22 basically, as one of eight companies that could help the  
23 epidemic, the opioid epidemic.

24 Q. And since you solved this motion and low  
25 perfusion problems, has Masimo continued to invest in

1 research and development in other areas?

2 A. Yes. Absolutely. Masimo's founding was all  
3 about innovation. I was 24 when I started Masimo. So we  
4 had to prove ourselves. So we have continued to, not only  
5 advance pulse oximetry, even though we made it 30 times  
6 better than what was out there before, but we had then taken  
7 the two-LED pulse oximeter to multi-LED we call rainbow« to  
8 measure 12 parameters noninvasively for the first time,  
9 including noninvasive hemoglobin, noninvasive carbon  
10 monoxide, methemoglobin, that have all been shown to save  
11 lives dramatically in hospitals.

12 Q. I wonder if you can just briefly describe, who is  
13 Cercacor, your other company?

14 A. Yes. In 1998, at the behest of shareholders and  
15 our board, we spun off a company called Masimo Laboratories  
16 at the time that we named Cercacor, which means closer to  
17 the heart. And Cercacor or Masimo Labs was to go work on  
18 nonvital signs measurements, like rainbow«, like measuring  
19 hemoglobin and hopefully noninvasive blood glucose, and  
20 that's what Cercacor is.

21 Q. And what's the -- is there a legal or technical  
22 relationship between Masimo and Cercacor?

23 A. Yes. At the time of the spinoff and later  
24 updated, we have a cross-licensing agreement between the two  
25 companies. So, basically, the two R&D organizations, Masimo

1 and Cercacor, can collaborate, because whatever they invent  
2 it's shared amongst each other for the various projects.

3 Q. And for the record could you identify  
4 Complainants' Exhibit 1612?

5 A. Yes, that is the latest cross-license agreement  
6 between Masimo Laboratories or Cercacor and Masimo  
7 Corporation.

8 Q. So tell me, today, or since the relevant periods  
9 in this case, what are the projects that Cercacor works on  
10 relating to this case?

11 A. Well, Cercacor is who developed rainbow<sup>®</sup>.  
12 rainbow<sup>®</sup> platform was supposed to be the platform that  
13 helped us to get to noninvasive glucose, but along the way  
14 we checked for measurements that were maybe slightly easier  
15 but a lot harder than pulse oximetry, like carbon monoxide,  
16 like hemoglobin. And we delivered. Those things worked and  
17 they have been in the market for over 15 years some of them.

18 Q. Well, let's call up that exhibit, the timeline,  
19 Complainants' Exhibit 1370, and let's take a look at pages 6  
20 and 7 of the timeline, because it does go many pages.

21 Can you show us from looking at the timeline in  
22 Exhibit 1370 what are some of the parameters and products  
23 introduced through the rainbow<sup>®</sup> research platform?

24 A. Yes. Beginning 2005, with SpCO, that's the  
25 noninvasive way of measuring carbon monoxide. Nothing else

1 is like it out there still. And it helps firefighters and  
2 people that may have been in a situation where they could  
3 have inhaled smoke and carbon monoxide to detect when their  
4 CO has gotten dangerous.

5 Q. Are you aware of any other companies that offer  
6 products in competition with these parameters shown in this  
7 timeline dealing with SpCO and methemoglobin and hemoglobin?  
8 Are you aware of any other competing commercial products?

9 A. No. No. Over the years we've seen announcements  
10 from a few companies, but nothing in the market. We are  
11 still the only company with these parameters. And, like I  
12 said, noninvasive hemoglobin has been proven to now reduce  
13 mortality by 30 percent in hospitals.

14 Q. Why is it called rainbow«?

15 A. Because we went from a two wavelengths of light  
16 to more than seven, like the colors of the rainbow, so we  
17 call it rainbow«.

18 Q. And did you patent some of the research that came  
19 out of the rainbow« research and development?

20 A. Yes. Absolutely.

21 Q. I just need you to identify for the record joint  
22 Exhibit 1, if we can call that up.

23 Can you identify that for the record?

24 A. Yeah, that is actually the '501 patent that's in  
25 this case that describes some of the inventions that we did

1 with rainbow«.

2 Q. And you're a named inventor on here?

3 A. Yes, I am.

4 Q. Can you identify for the record Joint Exhibit 2?

5 A. Yes.

6 MR. MUELLER: I'm sorry. I apologize for  
7 interrupting here. I do want to make an objection based on  
8 that last answer.

9 The alleged domestic industry products in this  
10 case for these patents are not the rainbow« sensors. So I'm  
11 going to object to testimony in which Mr. Kiani is trying to  
12 link these patents and suggest that the rainbow« sensors  
13 practice them.

14 The alleged products for these patents are the  
15 Masimo Watch, the alleged product I should say, for domestic  
16 industry. There's no contention in this case linking the  
17 Poeze patents to the rainbow« sensors, and it's far too late  
18 to make that now. So I object.

19 JUDGE BHATTACHARYYA: Mr. Re?

20 MR. RE: I'm doing no such thing. I'm just  
21 laying out basic facts. I haven't gone anywhere near the  
22 subtleties that Mr. Mueller is alluding to. I'm just  
23 setting forth facts. I'm not making any argument.

24 JUDGE BHATTACHARYYA: Is Masimo making a  
25 contention that the '501 patent covers the rainbow« sensor

1 products?

2 MR. RE: No. It's the research of the rainbow«  
3 that led to where we're going later in time. Correct. This  
4 is way earlier. I'm just introducing -- these are the  
5 patents that are in the investigation. Mr. Kiani is an  
6 inventor. I was just trying to make them of record. I  
7 wasn't trying to do anything further yet.

8 MR. MUELLER: Your Honor, so long as there's no  
9 contention by Masimo that the Poeze patents, the '501, '502,  
10 '648, practice the rainbow« sensor products or that those  
11 products are the domestic industry, then we can keep going.

12 JUDGE BHATTACHARYYA: Mr. Re, as I understood it,  
13 you would agree with that --

14 MR. RE: Yes, I do.

15 JUDGE BHATTACHARYYA: -- statement? All right.  
16 Then we can proceed.

17 Q. So the third patent is the -- can we identify for  
18 the record Joint Exhibit 3, which is the '648 patent, and  
19 call that up.

20 This is the third, as Mr. Mueller calls it, the  
21 Poeze patents?

22 A. Yes.

23 Q. And you're an inventor on all three of these,  
24 right?

25 A. Yes. Yes, I am.

1 Q. And who are these other gentlemen that are  
2 co-inventors with you?

3 A. Well, these were, some of them, my former  
4 colleagues, but my colleagues from Cercacor. You'll see,  
5 for example, Marcelo Lamago, who went to Apple in Cupertino;  
6 Sean Merritt, Cristiano Dalvi, who have now gone to Rockley,  
7 who is Apple-funded. But, yeah, these are my colleagues at  
8 the time at Cercacor.

9 Q. Could you just briefly explain how the ideas, the  
10 research that's embodied and disclosed in these patents,  
11 tell me, what was it you were doing that led to the  
12 disclosures of these three patents?

13 A. Yeah. We were trying to measure noninvasively  
14 hemoglobin and glucose, which are much more difficult  
15 measurements than oxygen. Just getting to the signal is  
16 really challenging. And we had come up with this idea of  
17 the active pulse.

18 Instead of your natural pulse, that can be very  
19 small from point 1 percent of the signal to maybe 4 or 5  
20 percent, we wanted to create an active pulse, so we created  
21 our own pulsation to create maybe 5 to 10 percent signal, AC  
22 signal.

23 Well, during that experimentation, one time the  
24 active pulse detector hammer had been left in, and when it  
25 pushed up against the digit we noticed the signal got



1 stronger, which was a surprise to us.

2 And that led us to this idea that, hey, maybe we  
3 should use actually a protrusion instead of the opposite,  
4 which we always had done, which was the cavity. And then,  
5 of course, along with that came problems of protrusion.  
6 There was now light piping issues, and so we had to account  
7 for it. But, yes, that's how this idea came about.

8 Q. Why were you surprised by the strengthening of  
9 the signal when applying an active pulse?

10 A. Well, because usually if you press against your  
11 digit you see it become white, the capillary blood bed  
12 pushes out of the way. So we thought that's going to cause  
13 the signal to go away, where actually at the right level it  
14 actually increases it. You can go too far and do what I  
15 just said or too little where it won't impact it. But at  
16 the right height you actually get a bigger signal.

17 Q. I'd like you to look at Fig. 3C of the Poeze  
18 patents, what we call multidetector patents, whatever.

19 Could you just tell me what you mean by the  
20 protrusion by looking at Fig. 3C?

21 A. Yeah, the protrusion is the 305, and you can see  
22 how it kind of comes up, it's got those four windows, 320,  
23 322, and 21, and 3, where the four detectors are underneath  
24 it where the light would go through from the top portion  
25 where the LED would shine through the digit if your finger

1 were inside this alligator clip. And that's where we  
2 protected the light from piping as well with those windows  
3 and the recession. Again, that, 305, is the protrusion.

4 Q. And you said that when you use the protrusion it  
5 caused problems with light piping, is that what I  
6 understood?

7 A. Yeah. It made it worse. So we had to take extra  
8 care to make sure that the light that you see by the  
9 detector has gone through the tissue, and that's where we  
10 basically created, again, this well, this time, you know,  
11 with obviously a cover, as a reasonable product, and we made  
12 sure that only the light that went through the tissue went  
13 to the photodetector.

14 Q. I understand you prepared a demonstrative to  
15 explain the ill effects of light piping; is that right?

16 A. Yes.

17 Q. If you can call up that demonstrative.

18 A. Yeah. So what you see here, on the left side,  
19 this is a reflectance mode. You see the light emitter  
20 diodes on the left, and the detector on the right. What you  
21 want is the light to go down to the tissue and come back up  
22 to the detector. But if you don't design this properly, you  
23 get light that goes from the LED directly to the  
24 photodetector, without going through the tissue.

25 And the same phenomenon exists also with the

1 transmissions. This is adhesive transmission sensor around  
2 the finger, and you can see how the light, instead of going  
3 right to the detector, some of it, if you're not careful,  
4 will go around and get to the detector without going through  
5 the tissue, which causes inaccuracies in the measurement.

6 Q. And if we go back to Fig. 3C, did I hear you or  
7 understand you, did the hole or the well, did that go all  
8 the way to the tissue in Fig. 3C?

9 A. It did. It did. And then down to the floor of  
10 the detector, with optical barriers in that well, the walls,  
11 to make sure only the light through the tissue gets to that  
12 photodetector that's sitting at the bottom of that hole.

13 Q. And did you have a reason or understanding why  
14 you know the industry did not understand the ill effects of  
15 light piping?

16 A. Yes. Yes. During the '90s, early '90s, we were  
17 developing the measured pulse oximeter, our main competitor,  
18 Nellcor, came with the first time a new improved sensor, and  
19 they had built it so it reduces the problem of emissions,  
20 electromagnetic radiation that by putting a Faraday shield  
21 around the detector, but because they weren't aware of the  
22 light piping, that bump created the cavity, like a fiber, so  
23 more light went from the LEDs to the detector and was  
24 causing all kinds of errors out there, but they didn't  
25 understand it. And so their improved product actually made

1 things worse.

2 Q. Okay. I'd like to change subjects now and talk  
3 about your consumer products.

4 What was Masimo's first consumer-focused product?

5 A. The iSpO2.

6 Q. And what is the iSpO2?

7 A. I think as the name maybe suggests it's a product  
8 that the pulse oximeter that connects to the smartphones,  
9 like an iPhone or tablet or iPad, and we have it in two  
10 versions, one with the finger sensor clip attached to the  
11 cable, that goes right to the phones, and one with a  
12 connector that allows you to plug in 50 different sensors we  
13 make from neonate to adult, from ear to forehead and finger  
14 to it.

15 Q. And did that technology that you incorporated  
16 with the iPhone, did that have your medical-grade technology  
17 in it?

18 A. Oh, yeah. I will not market any pulse oximeter  
19 that doesn't have our Masimo SET performance or very close  
20 to it, because I've seen the outcome difference. That's why  
21 for years we would not enter into this consumer stuff,  
22 because it would be toys, it wouldn't work. So, yeah, once  
23 we got the power consumption down, remember, the MS1 board I  
24 showed in '95, that consumed 4,500 milliwatts, so that could  
25 not be made into a wearable or a consumer product. So it

1 was down to -- when we got the power down to about 20  
2 milliwatts, we began to make these consumer products and  
3 products that were wearable.

4 Q. I'd like you to look at Complainants' Exhibit  
5 1511.

6 A. Yes.

7 Q. Would you identify for the record what is Exhibit  
8 CX-1511?

9 A. This is a press release, an announcement, that we  
10 also sent through what we call Livewire, which is an  
11 electronic email database of our customers, where we  
12 announced the availability of iSpO2, a debut of it, at the  
13 Consumer Electronics Show in January of 2013.

14 Q. And when you say Consumer Electronics Show, you  
15 showed this product at that show that year?

16 A. Yes.

17 Q. Prior to going to the Consumer Electronics Show,  
18 what other shows did you go to before then?

19 A. Only the clinical ones, like the anesthesiologist  
20 conference or critical care conference or nursing  
21 conference. This was our first time going to kind of a  
22 public consumer type of a marketplace.

23 Q. And did the iSpO2 device with the iPhone, did  
24 that attract some media coverage at CES?

25 A. That was a big hit. There was numerous, like 15,

1 20 different articles written about it, and put on the news  
2 about the availability of a medical-grade Masimo SET pulse  
3 oximeter for the first time available on these kinds of  
4 devices.

5 Q. And if I could show you Complainants' Exhibit  
6 1512, could you explain for the record what is this exhibit  
7 showing?

8 A. Yeah, I think this is just some of the -- kind of  
9 like the cutouts of some of these articles that had come  
10 out, 21 articles that had come out as of January 10th, 2013.

11 Q. And did Apple take notice of the notoriety you  
12 were receiving with your consumer product for use with the  
13 iPhone?

14 A. Yes. Within two to three months they contacted  
15 us, and they said you guys are the platinum of noninvasive  
16 monitoring, we want you to come down to Cupertino, we want  
17 to learn more, we'll sign your NDA, we want to work with you  
18 to integrate your technology into our products.

19 Q. Did you have such a meeting?

20 A. Yes, we did. I was personally there.

21 Q. And did Apple send you an agenda for the meeting?

22 A. Yes, they did.

23 Q. I'd like to show you an exhibit, which Apple has  
24 objected to, so I'm alerting Mr. Mueller, it's Exhibit 1539.

25 Could you --

1 O P E N S E S S I O N

2 BY MR. RE:

3 Q. When did you become interested in a  
4 wrist-wearable pulse oximeter?

5 A. Actually from the very beginning. When I started  
6 Masimo, I hoped to one day build a wrist-worn pulse  
7 oximeter, because I hoped to one day take the product out of  
8 the hospital into home for sleep analysis, for detecting  
9 babies that are about to die from sudden infant death  
10 syndrome, to even taking it to the gym, take it to people  
11 who are exercising. So that's been something since  
12 practically 1990, 1991 that I was --

13 Q. And why weren't you able to do it back then and  
14 just go on to the wrist?

15 A. As I mentioned, the power. Our technology, we do  
16 so much signal processing with the adaptive filter, it used  
17 to take a very sophisticated sharp chip from analog devices  
18 that consumed about 3,000 milliwatts. Fortunately over time  
19 these chips have gotten better and smaller and more power.

20 So, look, if I wanted to do conventional pulse  
21 oximeter, I could have made a wrist-worn device 30 years  
22 ago, but to make something that works accurately, reliably,  
23 continuously, it needed to be Masimo SET or very close, and  
24 that's what we were waiting for. And eventually we did get  
25 the power down to do that.

1 Q. When did you start getting -- submitting --  
2 spending serious resources towards pursuing a wrist pulse  
3 oximeter?

4 A. Right around the time we had the low power pulse  
5 oximeter, so around 2013, 2014, I remember 2014 we began  
6 actually a project at Cercacor to develop a wrist-worn pulse  
7 oximeter.

8 Q. And let's take a look at a document numbered  
9 CX-1482, if we can call that up.

10 Would you identify this document?

11 A. Yes. This is a Cercacor presentation on what we  
12 called the wrist-worn pulse oximeter or wearable rainbow«.

13 Q. If we can go to the picture, just the picture, on  
14 page 114, could you identify that physical?

15 A. Yes, mind you, this is a prototype, so it was  
16 okay to have all these cables dangling out, because this is  
17 for data collection. But the sensor is where that black  
18 part is on the wrist where it shines the LED, multiple LEDs,  
19 multiple detectors, to pick up, not just SpO2, but hopefully  
20 hemoglobin and CO and other measurements.

21 Q. What's the year of this presentation?

22 A. This presentation is 2016, I believe.

23 Q. And I'd like you to look at a physical exhibit  
24 that's in your room. If you look over at the table to your  
25 right, if you can call up and hold Complainants' physical



1 Exhibit 139 and let me know if you recognize that device.

2 Do you see it? Do you see the table next to you? To your  
3 right.

4 A. Oh.

5 Q. To your right. There we go.

6 A. I see, yes. This.

7 Q. Yes. What is CPX-139?

8 A. This is the actual physical representation of  
9 what's in that picture.

10 Q. And this is 2016, the presentation, if I  
11 remember, you said?

12 A. That is correct.

13 Q. Okay. I'd like you to go to the next exhibit,  
14 CX-1483.

15 Do you see this document?

16 A. Yes.

17 Q. I'd like you to go to the picture on page 2  
18 ending in 120.

19 Could you tell me what that is?

20 A. Yeah. This is -- we were trying to see how the  
21 measurement would work if it actually transmitted the signal  
22 straight from one end of the wrist to the other side. This  
23 is a transmission wearable wrist pulse oximeter, the giant  
24 black thing there is the photodetector, and the little  
25 circuitry someone is holding with their finger are the LEDs

1 on the other side.

2 Q. And what year is this watch prototype?

3 A. 2017.

4 Q. And can you look to your right, there's a  
5 physical, CPX-140, can you call that up, show it on the  
6 screen?

7 What is that physical?

8 A. Yeah, this is the actual, I guess, hardware  
9 manifestation of that image that you just saw.

10 Q. For the record, that picture on CPX-140 was  
11 ending in 120, the picture of this physical.

12 I'd now like you to look at CX-1520. If you  
13 could identify this document for the record.

14 A. Yeah, this is, I think, a presentation at  
15 Cercacor called the Hummingbird Project.

16 Q. And if you look at the picture on the page 15,  
17 ending in 086, could you describe that for the record?

18 A. Yes, that's just another update to what the  
19 wrist-worn pulse oximeter prototype looked like.

20 Q. And what was the point of this prototype?

21 A. It's to test the accuracy of it, not just in room  
22 air, but under the saturation, where we brought in  
23 volunteers, and by having them read a mixture of nitrogen  
24 and oxygen, we dropped them from room air of 100 percent to  
25 70 percent.

1 Q. I'd like -- what's the benefit of using a watch  
2 versus a product like the PPG we talked about in Exhibit  
3 691?

4 A. Well, we wanted something unobtrusive, because,  
5 as I mentioned earlier, in one of the biggest, I think,  
6 cases where this kind of product could be useful is for  
7 detecting opioid overdose. But of the hundred thousand  
8 people that died from opioid overdose last year, 80,000 were  
9 illicit users. In talking to some of those people, they  
10 were not going to wear a finger sensor that told everyone --  
11 signaled that they were potentially addicts.

12 So a watch could be something that's unobtrusive,  
13 it looks like something anyone would wear, and yet, if in  
14 the middle of the night opioid overdose stopped them from  
15 breathing, an alarm could go to wake them and eventually  
16 maybe to an ambulance to come rescue them.

17 Q. Exhibit 1493, do you recognize that document?

18 A. Yes, that's a Team Meeting presentation in  
19 December 2018.

20 Q. And I'd like you to go to page 10 of this  
21 presentation of 2018, at the very top, can we just blow up  
22 the first few lines on the Engineering Goals da Vinci.

23 A. Yes.

24 Q. And next to develop wrist-based hardware  
25 solution, what is designated in this presentation?

1           A.    That it's been 100 percent completed, that we  
2   have validated that we can measure SpO2 accurately with our  
3   wrist-worn pulse oximeter.

4           Q.    And was there also research going on on this  
5   subject at Masimo concurrently with Cercacor?

6           A.    Yes.  Yes, there was a friendly rivalry, a  
7   cooperation, but, yes, Masimo was working on their own  
8   version as well.

9           Q.    And where does all this research and development  
10   occur with Masimo and Cercacor?

11          A.    Masimo and Cercacor are literally two blocks from  
12   each other in Irvine, California.

13          Q.    Okay.  How involved were you with regard to the  
14   Masimo Watch project, you personally?

15          A.    Well, as I said, from almost the beginning I  
16   wanted to have it.  Towards the end, meaning the last  
17   several years, I became personally really involved, because  
18   I wanted to now see it come to market.

19                We were going after this opioid epidemic problem,  
20   and I really thought this watch could be a lifesaver.

21          Q.    I'd like you to -- we're going to go on the CBI  
22   portion.  This is Masimo confidential information.

23                (Whereupon, the hearing proceeded in confidential  
24   session.)

25

**APPX40229-40232**  
**ENTIRELY REDACTED**

1 O P E N S E S S I O N

2

3 JUDGE BHATTACHARYYA: Moving to the public  
4 record.

5 MR. MUELLER: May I proceed, Your Honor?

6 JUDGE BHATTACHARYYA: Yes, you may.

7 BY MR. MUELLER:

8 Q. Mr. Kiani, over the life of the company, fair to  
9 say that Masimo has focused, not exclusively, but has  
10 focused on the clinical setting?

11 A. Yes, that is correct.

12 Q. And, fair to say, the vast majority of the Masimo  
13 revenues over the years have been in that clinical setting?

14 A. Yes.

15 Q. Now you identified for Her Honor in your  
16 testimony earlier several products that you described as  
17 consumer products, right?

18 A. Yes.

19 Q. I think there's the SpO2 monitor, right?

20 A. iSpO2, yes.

21 Q. The MightySet; is that correct?

22 A. That is correct.

23 Q. And another one you mentioned was the Radius PPG,  
24 correct?

25 A. Yes, that is correct.

1 Q. Now, to be clear, all of these products that you  
2 described involve fingertip sensors, correct?

3 A. Correct.

4 Q. So let me just show you an example. This is the  
5 Radius PPG. If you could turn to, in your binder, sir, this  
6 is CX-0691. I believe it's at tab 2 in your binder.

7 A. In my direct binder?

8 Q. There should be another binder titled  
9 "Cross-examination."

10 A. I have not opened it yet.

11 Q. You can go ahead and open it, sir.

12 A. Okay.

13 MR. RE: I also get a copy, I assume? There's  
14 two sets.

15 MR. MUELLER: Yes.

16 MR. RE: Can you give us just one moment?

17 MR. MUELLER: Sure.

18 MR. RE: The witness is down the hall. We did  
19 not open the box, and it's being opened now in the witness  
20 room.

21 MR. MUELLER: Thank you.

22 THE WITNESS: This reminds me when my daughter  
23 took the LSAT remotely.

24 I have opened it.

25 Q. Take your time, and if you could, please, turn to

1 up in a moment here. If you could turn in the binder while  
2 we're pulling it up here to Fig. 3.

3 A. Fig. 3, yes. C, D, E, which one?

4 Q. This one right here, Fig. 3C --

5 A. Perfect. That's the one Mr. Re showed me.

6 Q. That's right. Now this is showing a finger clip  
7 sensor, correct, sir?

8 A. Yes, this is a finger clip sensor.

9 Q. And so the way this would work is a user would  
10 insert their finger into this device and then close it down,  
11 right?

12 A. Yes.

13 Q. And that region at the bottom center of the  
14 screen where it's labeled 322, 323, 320 and 305, you talked  
15 about that earlier with Mr. Re, correct?

16 A. Yes.

17 Q. And you told us about how the tissue would be on  
18 top of that sensor, correct?

19 A. Correct.

20 Q. And there's the holes that go all the way down to  
21 where the photodetectors reside, correct?

22 A. Correct.

23 Q. And readings are taken from those, correct?

24 A. Yes. You either accumulate or you parse, but,  
25 yes, you take those detector signals and measure what you



1 need to measure, in this case oxygen or hemoglobin or  
2 glucose.

3 Q. Now you would agree with me that nowhere in these  
4 patents is there a similar description, similar level of  
5 detail, for a watch, correct?

6 A. No, not for a watch. Although there is a  
7 wristband device, but there is a lot of description about  
8 this being used in different parts of the body, like the  
9 forehead, the ear, and the like. Different sizes of  
10 patients, from neonates to adults.

11 Q. Sir, stay with my question. Not a watch, right?

12 A. Well, there's a wrist-worn device, but because  
13 this would connect to a wrist-worn device, I assume that is  
14 not considered a watch, but, yes, there is a wrist-worn  
15 device shown.

16 Q. Sir, stay with my question. Not a watch.

17 A. Yes, not a watch. It doesn't have the clock.

18 Q. In fact, sir, as you told us earlier, Masimo, and  
19 apparently Cercacor, did work on watches in the mid 2010s,  
20 correct?

21 A. Well, once we reduced the power consumption of  
22 our algorithm, our set board, yes, we began trying to make  
23 wearables and consumer products.

24 Q. And the reduced power consumption that you're  
25 describing occurred in the mid 2010s, right?

1           A.    That is correct. To the best of my memory,  
2   that's when it happened.

3           Q.    And because you developed it in the mid 2010s, of  
4   course you didn't have possession of those particular ideas  
5   back at the time of the Poeze patents when they were filed,  
6   correct, sir?

7           A.    That's not true. Back even in '91 I had this  
8   idea of making a watch out of our technology.

9           Q.    Well, sir, I understand you had the idea. You  
10   had the aspiration. You hadn't actually pulled it off and  
11   come up with the engineering solution until much later,  
12   correct?

13          A.    Well, the engineering solution included power  
14   reduction and size reduction of our pulse oximeter  
15   technology. So we were working towards that. Hospitals  
16   don't need the power or size reduction because those devices  
17   get plugged to the wall by the bedside.

18                So the reason we were pushing and pushing to  
19   reduce the size, reduce the power, so we can make it  
20   portable, wearable consumer version.

21          Q.    I understand that was your goal, sir, but you  
22   just told me a couple minutes ago that you solved the power  
23   consumption problem in the 2010s, correct?

24          A.    Yeah. I don't have the exact date in my mind,  
25   but, yeah, right kind of before we began working on iSpO2,

1 and then MightySet on the watch we had gotten the power down  
2 to a level where it could be wearable and battery-operated.

3 Q. In the 2010s, correct?

4 A. Yes, sir, to the best of my memory, yes.

5 Q. Now because you came up with that in the 2010s,  
6 you were not in possession with that in 2008, correct?

7 A. I'm sorry. What are you -- oh, when we -- well,  
8 they're related. If you actually read the patent, it talks  
9 about putting the sensor anywhere on the body.

10 You're focusing on the watch. We focus on pulse  
11 oximetry, where in the body you could put it. And what this  
12 invention showed is that in difficult situations -- in this  
13 case hemoglobin or glucose where the signals are tiny -- or  
14 are or on the finger or maybe in situations where maybe on  
15 the forehead or wrist where the pulse ox is strong but that  
16 site is bad, this invention comes in handy to make the  
17 measurement.

18 Q. Sir --

19 A. We were in possession of it, yes.

20 Q. Sir --

21 A. With the power -- sorry.

22 Q. I didn't mean to interrupt you. Did you finish  
23 your answer?

24 A. No. I would say we were in possession of one  
25 piece, but we needed the other piece, the power consumption

1 to come down, to then put it together to make things like  
2 iSpO2 and eventually the watch.

3 Q. Sir, you were not in possession as of 2008 of the  
4 engineering solution to putting a pulse oximeter in a watch,  
5 correct?

6 A. Well, not all of the -- not all the components of  
7 it, but some of it, yeah, that's what this patent shows.

8 Q. Sir, you could not build a watch with a pulse  
9 oximeter in it; you did not have possession of that idea in  
10 2008, correct?

11 A. We did not have feasibility until maybe 2016,  
12 2017.

13 Q. Now the patent was filed, the original patent in  
14 the Poeze patent family, was filed in 2008, correct?

15 A. The provisional was filed in 2008, that's  
16 correct.

17 Q. And, in fact, it was filed on September 20 -- I'm  
18 sorry. I'll retract that.

19 It was filed in 2008, but the three patents that  
20 are asserted in this case in that same family were filed  
21 about 12 years later in September of 2020, correct?

22 A. I know that's -- I think when they fished. I  
23 don't know when they were filed. You'd have to talk to our  
24 lawyers. Obviously the disclosure is identical, all that  
25 changes are the claims, and I don't know when those claims

1 were first sought after.

2 Q. Well, let's pull up the Joint Exhibit that we  
3 were just looking at a moment ago, and let's look at the  
4 cover.

5 So we have here the '501 patent. This is one of  
6 the three asserted in this case, correct?

7 A. Yes.

8 Q. And let's go down to the filing date, which is in  
9 the left-hand side, midway down. And do you see, sir, it  
10 was filed on September 24th of 2020?

11 A. Yes, I see that. That's when those claims were  
12 filed.

13 Q. And let's take a look at JX-2, the '502 patent.  
14 We'll take you to the filing date for this one. September  
15 24th, 2020. Do you see that, sir?

16 A. Yes, I do.

17 Q. Very same day, right?

18 A. Yes.

19 Q. And let's go to JX-3, the '648 patent, and do you  
20 see, sir, that was filed on the very same day as well?

21 A. Yes.

22 Q. So you'd agree that the three patents in this  
23 family that are asserted in this case were filed on  
24 September 24th, 2020, right?

25 A. Yes.

1 Q. Now that's 12 years after the original  
2 provisional application, correct?

3 A. Yes.

4 Q. If we go back to the release dates of the Apple  
5 Watches, do you see the Series 6 was released on September  
6 18th, 2020?

7 A. Yes, I do see that.

8 Q. Very shortly before these applications were  
9 filed, correct?

10 A. Yes, correct.

11 Q. And, in fact, if we go to RX-0333, which is tab  
12 14 in your binder, sir.

13 A. Yes, I see the press release from Apple  
14 announcing the watch, Series 6.

15 Q. On September 15th of 2020, correct?

16 A. Yes.

17 Q. That's nine days before these three patent  
18 applications were filed, right?

19 A. Yes.

20 Q. And it's fair to say, sir, you know of no reason  
21 that these three patents could not have been filed earlier  
22 than September 24th, 2020, right?

23 A. Well, I think there were reasons it was filed  
24 then. I have a vague understanding of some of the reasons,  
25 but you should ask the lawyers who did it to why they did it

1 when they did it.

2 Q. Well, let me take you to your deposition. This  
3 is RX-1204. Let me take you to your deposition transcript  
4 at page 175, lines 14-17.

5 MR. RE: Objection. One moment. Mr. Kiani, do  
6 you have a copy of your deposition with you? It should be  
7 in one of your notebooks.

8 THE WITNESS: Well, yeah. Which tab am I looking  
9 at?

10 Q. Tab 1 in your Cross-Examination Binder. Take  
11 your time. Let me know when you're on page 175.

12 A. Yes.

13 Q. Are you there, sir?

14 A. I am.

15 Q. Line 14.

16 Question. And is there any reason that you know  
17 of that these three patents could not have been filed  
18 earlier than September 24th, 2020?

19 Answer. No.

20 Were you asked that question and did you give  
21 that answer, sir?

22 A. Yes, that is correct. That is my understanding  
23 at the time. I did not know.

24 Q. All right. Thank you, sir. You can put your  
25 deposition transcript aside for the moment.

1           Let me ask you about whether what was known in  
2   your view and what was not known with respect to the --  
3   these three patents on which you're a named co-inventor.

4           LEDs, light-emitting diodes, with multiple  
5   wavelengths had been used in physiological measuring devices  
6   before 2008, correct?

7           A.    Yes.

8           Q.    Before 2008 there had been physiological  
9   measuring devices with multiple LEDs emitting different  
10   wavelengths of light, correct?

11          A.    That was Masimo's invention, rainbow«.

12          Q.    Before 2008, correct?

13          A.    That is correct.

14          Q.    And those were in public sale before 2008,  
15   correct?

16          A.    Correct.

17          Q.    And there was also physiological devices with  
18   multiple photodiodes before 2008, correct?

19          A.    Correct.

20          Q.    So, in fact, there were multiple detector  
21   physiological devices before 2008, correct?

22          A.    That's correct.

23          Q.    Now you weren't the first to invent photodiodes  
24   configured to receive light attenuated by the tissue of a  
25   user, right?



1 A. That is correct.

2 Q. In fact, that was an old idea?

3 A. Yes, absolutely. Sorry.

4 Q. I'm sorry. I didn't mean to interrupt.

5 A. I apologize. I was just saying that concept, of  
6 course, dates back to even the oximeters before pulse  
7 oximeters, before Aoyagi invention, yes.

8 Q. You'd agree with me, sir, that Masimo wasn't the  
9 first to invent a user-worn device that could take  
10 physiological measurements from photodiodes, right?

11 A. That is correct.

12 Q. Nor the first to invent a user-worn device that  
13 could transmit measurements wirelessly, right?

14 A. Yes, I believe -- I believe that's correct, yes.

15 Q. Nor the first to invent a user-worn device with a  
16 touchscreen, correct?

17 A. Yeah, I think so. I think you're right. We were  
18 the first, but I don't believe this patent was first to  
19 disclose that.

20 Q. It came before this patent; is that right, sir?

21 A. Yes, the way you asked it, yeah.

22 Q. And, of course, wrist straps for various types of  
23 devices have been around forever, right?

24 A. Yes, they have.

25 Q. Now let's talk a little bit about light piping, a

1 MS. SWAROOP: Your Honor, Complainants' next  
2 witness will be Mr. Ammar Al-Ali, and Mr. Jensen will be  
3 conducting that examination.

4 MR. MUELLER: Your Honor, Sarah Frazier will be  
5 conducting the cross-examination.

6 JUDGE BHATTACHARYYA: Thank you.

7 MR. JENSEN: Good afternoon, Your Honor. This is  
8 Steve Jensen.

9 Mr. Al-Ali, are you comfortable and do you have  
10 your book?

11 THE WITNESS: Yes. Good afternoon.

12 MR. JENSEN: May we begin, Your Honor?

13 JUDGE BHATTACHARYYA: I'll swear in the witness  
14 first before we proceed further.

15 Mr. Al-Ali, did I pronounce it right?

16 THE WITNESS: That's correct.

17 JUDGE BHATTACHARYYA: Welcome. Thank you for  
18 coming. Do you understand you're under an obligation to  
19 tell the truth here today?

20 THE WITNESS: I do.

21 AMMAR AL-ALI,  
22 having been first duly sworn and/or affirmed  
23 on his oath, was thereafter examined and testified as  
24 follows:

25 JUDGE BHATTACHARYYA: Thank you.

1 DIRECT EXAMINATION

2 BY MR. JENSEN:

3 Q. Mr. Al-Ali, could you please state and spell your  
4 name for the record?

5 A. Ammar Al-Ali, A-M-M-A-R, A-L hyphen A-L-I.

6 Q. And who is your current employer?

7 A. Masimo Corporation.

8 Q. When did you start at Masimo?

9 A. I started April 1995.

10 Q. Could you just briefly explain your job history  
11 at Masimo since you started?

12 A. Yes. I started at Masimo in '95 as a software  
13 engineer, and then moved from that to manage the engineering  
14 department. I worked in the early days of '95 to about 2000  
15 on the Masimo saturation algorithm.

16 And then after that our RAD system, which is a  
17 medical device, and then after that I worked on the rainbow  
18 system, and lately I've been working on wearable  
19 technologies.

20 Q. And what are your current responsibilities at  
21 Masimo?

22 A. Right now I oversee the technology development of  
23 the company.

24 Q. Okay. And you mentioned wearables in your  
25 previous answer. Did there come a point in time when from

1 your technology perspective the Masimo wrist pulse oximeter  
2 project became more formal?

3 A. Yes. I started looking into measuring the wrist  
4 somewhere around 2014, 2015. Did some feasibility work  
5 there. And then started again in 2017 to 2018. And in 2019  
6 we actually put a complete team to go after it, expanded the  
7 team so we have enough support from all disciplines of the  
8 engineering department.

9 Q. And did you file any patents back with that early  
10 work that you did?

11 A. Yes. I did file a patent on 2015 based on that  
12 initial work.

13 Q. And can you find in your book Complainants'  
14 Exhibit 4? Or we'll also pull it up on the screen. And let  
15 us know if you recognize that patent.

16 A. Yes, I do recognize that patent.

17 Q. And is this one of the patents that you were  
18 referring to that stemmed from the work you mentioned in  
19 2014 and 2015?

20 A. That's correct. This was from the 2015 time,  
21 yes.

22 Q. And you're an inventor on this patent, right?

23 A. Yes, I am.

24 Q. What was your involvement in this patent?

25 A. I am the designer for the and the inventor for

1 the subject matter. I gave disclosure to the attorneys to  
2 actually file the patent.

3 Q. Okay. And then you said that things started  
4 from -- I think you said working more with a team happened a  
5 little later.

6 What started happening then when you picked it  
7 back up, I think you said?

8 A. Oh, in 2019 we put a complete team behind this  
9 technology. We hired mechanical engineers, electronic  
10 engineers, and software. So we actually started making the  
11 sensor and trying to optimize its performance.

12 Q. And when did Masimo have its own wrist pulse  
13 oximeter devices with sensing on the wrist?

14 A. This would be late 2019.

15 Q. And could you please on the -- it's on the stand  
16 that's behind you -- or someone might have put it next to  
17 you, please find Complainants' physical exhibit 22. It's  
18 either there or it's on the cart.

19 A. Oh, it's on the cart.

20 Q. Number 22.

21 A. I found it.

22 Q. Okay. Do you recognize Complainants' Exhibit 22?

23 A. Yes. It's one of our early sensors.

24 Q. Can you show us just on your camera there, not on  
25 the ELMO, but just on the camera what you're holding?

1 A. (Complying.)

2 Q. And do you recognize that sensor?

3 A. Yes, I do.

4 Q. And when was it made?

5 A. This sensor was made in October 2019.

6 Q. How can you tell when it was made?

7 A. I do remember that, but also it has the labels on  
8 it.

9 Q. And maybe you could put it on the ELMO so that we  
10 can see that, what you're looking at. There we go.

11 So you were looking -- you were mentioning some  
12 labels. Are those the labels down there?

13 A. Yes, these are the labels, and 10-23-19, this is  
14 when it was actually used for a Desat study.

15 Q. When you say "Desat study," what do you mean by  
16 that?

17 A. This is a study that we do to evaluate the  
18 accuracy of the product. We bring in volunteers and we  
19 attach the sensor to their wrist and make them breathe a  
20 different mixture of oxygen and nitrogen to change the SpO2  
21 in their blood. So typically that study we take a person  
22 from about 100 percent, which is normal, down to about 70  
23 percent.

24 Q. On the back of the sensor head of that watch, is  
25 there a label?

1 MR. JENSEN: Actually, Your Honor, I should have  
2 said earlier we were on the confidential record as soon as I  
3 started pulling up these samples. I would like to be on the  
4 confidential CBI for Masimo at this point.

5 (Whereupon, the hearing proceeded in confidential  
6 session.)

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**APPX40346-40371**  
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1 C E R T I F I C A T E

2 TITLE: CERTAIN LIGHT-BASED PHYSIOLOGICAL MEASUREMENT DEVICES  
3 AND COMPONENTS THEREOF

4 INVESTIGATION NO.: 337-TA-1276

5 HEARING DATE: June 6, 2022

6 LOCATION: Washington, D.C. - Remote

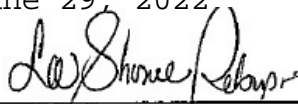
7 NATURE OF HEARING: Evidentiary Hearing

8 I hereby certify that the foregoing/attached  
9 transcript is a true, correct and complete record of the  
above-referenced proceedings of the U.S. International Trade  
Commission.

10 Date: June 29, 2022

11 Signed:

ss//



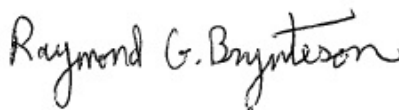
12 Signature of the Contractor or the Authorized Contractor's  
Representative

13

14 I hereby certify that I am not the court reporter  
and that I have proofread the above-referenced transcript of  
15 the proceedings of the U.S. International Trade Commission  
against the aforementioned court reporter's notes and  
16 recordings for accuracy in transcription in the spelling,  
hyphenation, punctuation and speaker identification and did  
17 not make any changes of a substantive nature. The  
foregoing/attached transcript is a true, correct and  
complete transcription of the proceedings.

18 Signed:

19 ss//



20

21 I hereby certify that I reported the  
above-referenced proceedings of the U.S. International Trade  
Commission and caused to be prepared from my record media  
22 and notes of the proceedings a true, correct and complete  
verbatim recording of the proceedings.

23 Signed:

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**Appx40375**

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# UNITED STATES INTERNATIONAL TRADE COMMISSION

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In the Matter of

Investigation No.

CERTAIN LIGHT-BASED PHYSIOLOGICAL

337-TA-1276

MEASUREMENT DEVICES AND COMPONENTS

THEREOF

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## OPEN/CLOSED SESSIONS

Pages: 283 through 596

Place: Washington, D.C.

Date: June 7, 2022

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**Appx40376**

1 UNITED STATES INTERNATIONAL TRADE COMMISSION

2 Washington, D.C.

3 Before the Honorable Monica Bhattacharyya

4 Administrative Law Judge

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6 -----x

7 In the Matter of Investigation No.

8

9 CERTAIN LIGHT-BASED PHYSIOLOGICAL 337-TA-1276

10 MEASUREMENT DEVICES AND COMPONENTS

11 THEREOF

12 -----x

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15 EVIDENTIARY HEARING

16 Tuesday, June 7, 2022

17 Volume II

18

19

20 The parties met via remote videoconferencing  
21 pursuant to notice of the Administrative Law Judge at 9:30  
22 a.m. Eastern.

23

24

25 Reported by: Linda S. Kinkade RDR CRR RMR RPR CSR

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2 [All parties appeared via remote videoconferencing and/or  
3 telephonically.]

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12 \*\*\* Index appears at end of transcript \*\*\*

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**APPX 40407-40422**  
**ENTIRELY REDACTED**

**APPX40431-40434**  
**ENTIRELY REDACTED**

1 O P E N S E S S I O N

2 MS. SWAROOP: Your Honor, for our next witness,  
3 Complainants call Bilal Muhsin. We're just getting him set  
4 up in the witness room.

5 JUDGE BHATTACHARYYA: Okay.

6 MR. MUELLER: Your Honor, I'll be conducting this  
7 cross-examination.

8 JUDGE BHATTACHARYYA: Thank you.

9 MR. MUELLER: Are we back on the public record,  
10 Your Honor?

11 JUDGE BHATTACHARYYA: Yes, we are.

12 MR. MUELLER: Okay. Thank you, Your Honor.

13 MS. SWAROOP: Our witness is ready.

14 Good morning, Mr. Muhsin.

15 JUDGE BHATTACHARYYA: Good morning. Could you  
16 help me pronounce your name again?

17 THE WITNESS: Bilal.

18 JUDGE BHATTACHARYYA: And the last name?

19 THE WITNESS: Muhsin.

20 JUDGE BHATTACHARYYA: Okay. Mr. Muhsin, thank  
21 you for coming here today. Do you understand you're under  
22 an obligation to tell the truth in your testimony?

23 THE WITNESS: I do.

24 BILAL MUHSIN,

25 having been first duly sworn and/or affirmed

1 on his oath, was thereafter examined and testified as  
2 follows:

3 DIRECT EXAMINATION

4 BY MS. SWAROOP:

5 Q. Good morning, Mr. Muhsin.

6 A. Good morning.

7 Q. Could you please describe your current  
8 employment?

9 A. I'm the Chief Operating Officer at Masimo.

10 Q. How long have you held that position?

11 A. Since 2019.

12 Q. What are your responsibilities as the Chief  
13 Operating Officer at Masimo?

14 A. I oversee R&D, regulatory, quality, operations,  
15 and commercial for Masimo, and clinical affairs as well.

16 Q. Mr. Muhsin, what is the Masimo Watch project?

17 A. It is a project that formally started in 2019.  
18 It's about a design of a wrist sensor that's able to  
19 calculate pulse oximetry, the SpO2 reading, and has other  
20 functionalities that a watch would have.

21 Q. What is your role in the Masimo Watch project?

22 A. I'm no longer a hands-on engineer, but I do  
23 oversee the entire R&D development, the operation side, and  
24 the commercialization side of the product.

25 Q. You mentioned that the Masimo Watch project

1 formally started in 2019. What did you mean by that?

2 A. It started in 2019 because, formally I said,  
3 which is a W1 project, we had many iterations of wrist  
4 sensors that we worked on prior, between us and our sister  
5 company Cercacor. So, technically, we had a lot of work  
6 done prior to 2019 on the project, but that's when it  
7 formally started for the W1.

8 MS. SWAROOP: And I'm going to be going into some  
9 confidential material, so I would like to go on the CBI  
10 record for Masimo.

11 JUDGE BHATTACHARYYA: Moving on to the Masimo  
12 confidential record.

13 (Whereupon, the hearing proceeded in confidential  
14 session.)

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**APPX40438-40442**  
**ENTIRELY REDACTED**

**APPX40483**  
**ENTIRELY REDACTED**

1 O P E N S E S S I O N

2

3 MS. SWAROOP: Are we on the public record now?

4 JUDGE BHATTACHARYYA: Yes, we are.

5 MS. SWAROOP: Thank you, Your Honor.

6 Mr. Scruggs, do you have a binder with you there  
7 in the room?

8 THE WITNESS: Yes, I have a binder.

9 MS. SWAROOP: We are ready to proceed. Before we  
10 begin, you're a little soft-spoken, so I would just ask that  
11 you try and speak as close to the mic as you can.

12 THE WITNESS: Sounds good.

13 JUDGE BHATTACHARYYA: Welcome, Mr. Scruggs. Do  
14 you understand that you are under an obligation to tell the  
15 truth here today?

16 THE WITNESS: Yes, I do.

17 STEPHEN SCRUGGS,  
18 having been first duly sworn and/or affirmed  
19 on his oath, was thereafter examined and testified as  
20 follows:

21 JUDGE BHATTACHARYYA: You may proceed, counsel.

22 DIRECT EXAMINATION

23 BY MS. SWAROOP:

24 Q. Good morning, Mr. Scruggs. Could you please  
25 state and spell your last name for the record?



1           A.    My name is Stephen Scruggs, and my last name is  
2 spelled S-C-R-U-G-G-S.

3           Q.    Where do you work?

4           A.    I work at Masimo Corporation.

5           Q.    How long have you worked there?

6           A.    I've worked there for almost ten years now. My  
7 ten-year anniversary will be in July.

8           Q.    What is your current position at Masimo?

9           A.    I'm the Director of Sensor Design.

10          Q.    How long have you had that position?

11          A.    I have had that position for a little over a year  
12 now.

13                MS. SWAROOP: I am going to go on the Masimo CBI  
14 record for essentially all of Mr. Scruggs' testimony, so I  
15 would like to designate the record accordingly.

16                JUDGE BHATTACHARYYA: Moving to the Masimo  
17 confidential record.

18                (Whereupon, the hearing proceeded in confidential  
19 session.)

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**APPX 40486-40506**  
**ENTIRELY REDACTED**

**APPX40512-40521**  
**ENTIRELY REDACTED**

**APPX 40525-40528**  
**ENTIRELY REDACTED**

1 information, because we're on the public record.

2 These are readings taken of the Masimo Watch  
3 articles or physicals that you showed to our technical  
4 experts, Professors Warren and Sarrafzadeh, during the March  
5 14th, 2022 demonstrations.

6 Do you recall that demonstration that day, sir?

7 A. Yes, I do.

8 Q. Okay. And various physicals, as Masimo refers to  
9 them, were presented that day by you, right?

10 A. Yes, that's correct.

11 Q. Now you handled them yourself, correct?

12 A. Yes.

13 Q. You did not permit Apple's experts to themselves  
14 operate the devices, take readings on their own bodies,  
15 correct?

16 A. Yes, that's correct.

17 Q. That is to say, you took the readings and you  
18 only let the experts watch once you were satisfied that a  
19 reading had been taken, correct?

20 A. The experts were in the room the whole time  
21 during the demonstration, so they could see the entire  
22 demonstration.

23 Q. But, sir, stay with my question. You only let  
24 the experts read the numbers on the devices when you were  
25 satisfied with the readings, correct?

1 A. They were able to see the readings the entire  
2 time that I was doing the demonstration.

3 Q. Now they asked you for permission to also use a  
4 finger clip sensor as a reference device; isn't that true?

5 A. I don't recall that.

6 Q. You didn't permit them to, did you.

7 A. We did not use a reference device.

8 Q. By the way, using reference devices, you know  
9 what that means, right?

10 A. Yes, I do.

11 Q. Using reference devices is using a device to  
12 compare the accuracy of one device against another, correct?

13 A. Yes, that's correct.

14 Q. It's a very common thing in the industry in which  
15 you work, right, sir?

16 A. I don't know that it's common, but I know that  
17 that's done.

18 Q. And you've done it yourself.

19 A. I don't know that I've used a reference device on  
20 myself. I know that during clinical studies we'll sometimes  
21 use reference devices.

22 Q. And by "we" you mean Masimo?

23 A. Yes, that's correct.

24 Q. Okay. Now if we look at the data here, we have  
25 blood oxygen on the left and pulse rate on the right. Do

1 you see that, sir?

2 A. Yes.

3 Q. And there are various numbers, which I will  
4 represent to you were recorded by our experts. You have no  
5 reason to quarrel with those numbers, do you?

6 A. I would think that, if your experts recorded  
7 them, that it is likely they were displayed.

8 Q. And do you see there's lists, CPX numbers, that  
9 correspond to various devices, including the ones you  
10 testified about earlier?

11 A. Yes, I see those.

12 Q. Now these demonstrations were taken where you  
13 were sitting at a table, correct?

14 A. Yes, I was sitting.

15 Q. And you were there for about 75 minutes. Do I  
16 have that right, sir?

17 A. I don't remember the specific time, but that  
18 sounds about right.

19 Q. And you were sitting the entire time, correct?

20 A. Yes, I was sitting during the demonstrations.

21 Q. And I really don't mean to be flip in my next  
22 question. You didn't go out for a jog midway through, did  
23 you.

24 A. No, I did not go for a jog.

25 Q. All right. You remained sitting, correct?

1 A. Yes.

2 Q. So let's look at these readings. On the left we  
3 have blood oxygen, and do you see in the top row, the  
4 variation was between 95 percent and 99 percent? Do you see  
5 that?

6 A. Yes, I see those three numbers reported.

7 Q. Now on the next row down we have a variation of  
8 97 to 81. Do you see that?

9 A. Mm-hmm.

10 Q. Now a reading of 81 percent can be cause for  
11 concern, correct?

12 A. I'm not a medical professional, so I don't know  
13 what would be cause for concern.

14 Q. Well, sir, you're one of the leaders of the  
15 sensor group at Masimo, aren't you?

16 A. Yes, of the mechanical design group.

17 Q. And you understand, sir, that a reading at 81 is  
18 a cause for concern of a user of these types of devices,  
19 correct?

20 A. I think I'd want to talk to one of our clinicians  
21 or a doctor.

22 Q. So you don't know one way or the other?

23 A. I don't know what value would be cause for  
24 concern.

25 Q. Well, you'd agree with me that the difference



1 between an 81 reading and a 97 reading on the same subject  
2 sitting at the same table is a very significant variation,  
3 isn't it?

4 A. I definitely see that that's a variation of 16  
5 percent SpO2.

6 Q. That's a poorly functioning blood oxygen sensor,  
7 isn't it.

8 A. I don't know that variation of 16 personnel means  
9 that it was poorly performing, but I do see variation.

10 Q. Do you consider that good performance?

11 A. I don't think there's enough data here to  
12 quantify whether or not it's good or bad performance.

13 Q. Let's go to the next row. The next device  
14 measured your blood oxygen level at 100 percent, correct?

15 A. Yes, I see that.

16 Q. With no variation at all, right?

17 A. I see that.

18 Q. Now, in fact, these devices had a cap at 100  
19 percent, didn't they.

20 A. I don't believe the devices display values over  
21 100.

22 Q. So if there was some sort of reading that hit the  
23 top of the charts, it's going to be listed as 100 no matter  
24 what the particulars, correct?

25 A. Yes, that's how all pulse oximeters report

1 values.

2 Q. And the next row down has 100, 100, 100, 100,  
3 100, right?

4 A. I see that, yes.

5 Q. Same with the one below that, correct?

6 A. Mm-hmm.

7 Q. And then below that we have 99.4, 100, 100. Do  
8 you see that?

9 A. Yes, I do.

10 Q. And then three 98s, right?

11 A. Yes.

12 Q. So we have a variation from device to device from  
13 81 to 100, correct?

14 A. Yes. The reported values here, I see 81 and I  
15 CDX-100.

16 Q. Same person, sitting at the same table, in the  
17 same session, there is variation from 81 to 100, correct?

18 A. Yes, I see that.

19 Q. Pulse rate, right-hand side of the screen, let's  
20 take a look at the readings.

21 First device, 125, 113, 94, correct?

22 A. Yes.

23 Q. Now 125 is a pretty high pulse rate, isn't it?

24 A. Yes.

25 Q. It would indicate that you might be, in fact,

1 running, at least at a very, very brisk walk, correct?

2 A. Or stressed, yes.

3 Q. Or very stressed. That could be another reason  
4 why the heart rate is extremely high, correct?

5 A. Yes.

6 Q. Now the next row down we have in the 90s and then  
7 as low as 82, correct?

8 A. Yes, I see that.

9 Q. And, again, this is you being measured, right?

10 A. Mm-hmm.

11 Q. Same person, right, sir?

12 A. Yes.

13 Q. Same table, same session.

14 A. Correct.

15 Q. The next row down, the device measured your pulse  
16 rate at 140 and then 52. Do you see that?

17 A. Mm-hmm. I see that.

18 Q. 140 is a very high pulse rate, correct?

19 A. Yes.

20 Q. 52 is extremely low. That's indicative of  
21 somebody who might be sleeping or very not stressed,  
22 correct?

23 A. Yes, 52 is lower than 140.

24 Q. And the device, same device, CPX-052C, measured  
25 the same person's pulse rate as 140 and then 52, correct?

1 A. Yes, at different points in time.

2 Q. Now there's other numbers listed below for the  
3 other devices, correct?

4 A. I see that.

5 Q. But, again, if we look at the sum total of these  
6 we have variation of 52 to 140 as well as numbers in the  
7 90's, 80's, and 100's, correct?

8 A. I see that variation, yes.

9 Q. And this variation, again, was the same subject,  
10 same session, right?

11 A. Yes, these values were taken on me during the  
12 same session.

13 Q. And you never once got up, correct?

14 A. I did not get up.

15 MR. MUELLER: At this point, Your Honor, we need  
16 to go on the Masimo confidential record.

17 (Whereupon, the hearing proceeded in confidential  
18 session.)

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**APPX40547-40555**  
**ENTIRELY REDACTED**

**APPX 40560-40574**  
**ENTIRELY REDACTED**

1 O P E N S E S S I O N

2

3 MR. LAQUER: Good afternoon.

4 JUDGE BHATTACHARYYA: Good afternoon. I see  
5 Mr. Young is before us here.

6 THE WITNESS: Good afternoon, Your Honor.

7 JUDGE BHATTACHARYYA: Good afternoon. Do you  
8 understand that the testimony -- that you are under an  
9 obligation to tell the truth in your testimony today?

10 THE WITNESS: Yes, I do.

11 MICAH YOUNG,

12 having been first duly sworn and/or affirmed  
13 on his oath, was thereafter examined and testified as  
14 follows:

15 DIRECT EXAMINATION

16 BY MR. LAQUER:

17 Q. Can you please state your name?

18 A. Micah Young.

19 Q. What is your job title?

20 A. I'm Masimo's CFO and Executive Vice President.

21 Q. When did you join Masimo?

22 A. In October of 2017.

23 Q. What's your educational background?

24 A. I have a Bachelor of Science in accounting as  
25 well as Criminal Justice, and that's from Indiana Wesleyan

1 University, and I earned my CPA shortly thereafter, although  
2 I'm currently inactive.

3 Q. What are your responsibilities as Masimo's CFO  
4 and Executive VP?

5 A. I'm responsible for all aspects of financing,  
6 including accounting, financial planning and analysis, tax  
7 and investor relations.

8 Q. How many people does Masimo employ in its  
9 financial department?

10 A. We have just over a hundred employees in the  
11 finance department.

12 Q. And who do you report to?

13 A. I report directly to Joe Kiani.

14 Q. Let's look at Complainants' Exhibit 1637, if you  
15 could tell me whether you recognize this.

16 A. Yes, that's our latest Earnings Report for fiscal  
17 year 2021.

18 Q. Let's turn to page 17 of the exhibit. Could you  
19 tell me why did Masimo include the Masimo W1 watch in its  
20 2021 Earnings Report here?

21 A. Well, the Masimo W1 watch is a top priority for  
22 the company, and we've invested significant dollars over the  
23 years to develop the watch and other wrist-worn devices, and  
24 we wanted to also show investors that this is going to  
25 become a larger part of our revenue earnings going forward.



1 Q. Please turn to page 19 of the exhibit. Can you  
2 describe what is shown here?

3 A. Yes. This slide shows our Sound United  
4 acquisition. We paid just over a billion dollars for Sound  
5 United. That acquisition closed in April of this year.

6 Sound United is a premium consumer technology  
7 leader with premium audio brands like Denon, Marantz, Bowers  
8 & Wilkins, as well as Polk Audio, and they have over 20,000  
9 points of retail distribution.

10 Q. And why did Masimo pay over one billion dollars  
11 for Sound United?

12 A. If you look at the next slide, you'll see it's a  
13 strategic priority for the company, and if you look  
14 underneath cross-leveraging our core competencies and  
15 capabilities, you'll see where this acquisition is strategic  
16 for us and it helps us bring Masimo W1 watch to consumers  
17 and bring it from our technologies from the hospital into  
18 the home.

19 Q. Let's take a look next at Complainants' Exhibit  
20 CX-1630. Let me know whether you recognize this.

21 A. Yes. That's our form 10-K for fiscal year 2020,  
22 which is ending January 2nd, 2021.

23 Q. Please turn to page 40 of the exhibit. The last  
24 paragraph there begins with:

25 Continuing technological advances and new product

1 introductions within the medical device industry place our  
2 products at risk of obsolescence. For example, in September  
3 2020 Apple Inc. announced that its Apple Watch Series 6  
4 includes a pulse oximetry monitoring feature, which may  
5 compete with certain of our existing products and products  
6 in development, including the consumer versions of our iSpO2  
7 and MightySat pulse oximeters.

8 Why did Masimo include that statement in its  
9 10-K?

10 A. Well, at that time Apple just launched the Watch  
11 6 Series, and we were concerned that the public would rely  
12 on it for pulse oximetry rather than our other pulse  
13 oximetry devices we have launched over the years, in  
14 addition to the W1 watch that we were -- that we -- had been  
15 in development during that time. So we disclosed it in the  
16 10-K as a risk factor at that time.

17 MR. LAQUER: Your Honor, at this point I'd like  
18 to go on Masimo's confidential record in order to discuss  
19 CBI.

20 (Whereupon, the hearing proceeded in confidential  
21 session.)

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**APPX40579-40614**  
**ENTIRELY REDACTED**

1 Q. You'll agree that the Ember« is a small, niche  
2 product, right?

3 A. It is. It is marketed to elite athletes, who do  
4 things like marathons, Tour de France type of stuff, Ironman  
5 Triathlons, those kinds of things, yes.

6 Q. Approximately how many Ember« units does Cercacor  
7 sell every year?

8 A. Oh, in a given year, between 30 and 50.

9 Q. That's 30 and 50, not 30 and 50,000, right?

10 A. I'm talking about units, yes.

11 Q. Okay, 30 and 50 units.

12 MR. COX: No further questions. Thank you.

13 MR. LAQUER: I have no further questions.

14 JUDGE BHATTACHARYYA: Thank you, Mr. Hammarth.

15 THE WITNESS: Thank you.

16 MR. LAQUER: Complainants next call Daniel  
17 McGavock.

18 JUDGE BHATTACHARYYA: Good afternoon,  
19 Mr. McGavock.

20 THE WITNESS: Good afternoon.

21 JUDGE BHATTACHARYYA: Do you understand you're  
22 under an obligation to tell the truth in your testimony here  
23 today?

24 THE WITNESS: Yes, I am.

25 DANIEL M. MCGAVOCK,

1                   having been first duly sworn and/or affirmed  
2   on his oath, was thereafter examined and testified as  
3   follows:

4                   JUDGE BHATTACHARYYA: Thank you.

5                   DIRECT EXAMINATION

6   BY MR. LAQUER:

7           Q.    Could you state your name?

8           A.    Daniel M. McGavock.

9           Q.    What do you do professionally?

10          A.    I'm a vice president at Charles River Associates,  
11   and I'm the practice leader of the intellectual property  
12   practice, and I specialize in financial and economic  
13   consulting, primarily focused on intellectual property  
14   matters, both in litigation context as well as outside of  
15   litigation for strategy and transactional purposes.

16          Q.    Could you briefly describe your educational  
17   background?

18          A.    Yes. I earned a Bachelor of Science degree in  
19   accounting from Indiana University in 1984, and I'm also a  
20   certified public accountant. I've been a CPA since 1985.

21          Q.    Do you have prior experience in ITC  
22   investigations?

23          A.    Yes, I do. I've worked on several investigations  
24   on behalf of both Complainants and Respondents.

25               MR. LAQUER: Your Honor, Complainants proffer

1 Mr. McGavock as an expert on financial matters, including  
2 economic, domestic industry, bond, and commercial success.

3 MR. MUELLER: No objection, Your Honor.

4 JUDGE BHATTACHARYYA: At this time Mr. McGavock  
5 is admitted as an expert in financial matters, including  
6 economic, domestic industry, bond, and commercial success.

7 Q. Mr. McGavock, do you have an opinion regarding  
8 the economic prong of domestic industry requirement in this  
9 investigation?

10 A. Yes. It's my opinion that Masimo's domestic  
11 investments in plant and equipment as well as labor or  
12 capital are both quantitatively and qualitatively  
13 significant in accordance with the requirements of section  
14 337.

15 Q. What work did you do in preparing your opinion?

16 A. Well, I first -- I gained an understanding of the  
17 patents and the products at issue, and then I also gained a  
18 thorough understanding of the appendices that Mr. Young went  
19 through in detail, and the sources of the information, how  
20 the information was compiled, and I also did some  
21 independent research.

22 Q. Did you consider Mr. Hammarth's appendix also?

23 A. Yes, I did.

24 Q. All right. And can you describe your independent  
25 research?

1           A.    Yes.  Well, one of the, I think, most important  
2   elements of my work was to actually visit the domestic  
3   facilities where the research and development activities are  
4   taking place in Irvine, not only research and development,  
5   but manufacturing activities as well.

6                   (Whereupon, the hearing proceeded in confidential  
7   session.)

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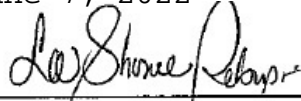
**APPX40631-40634**  
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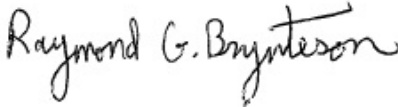



**APPX 40652-40655**  
**ENTIRELY REDACTED**

**APPX 40658-40662**  
**ENTIRELY REDACTED**

1 C E R T I F I C A T E  
2 TITLE: CERTAIN LIGHT-BASED PHYSIOLOGICAL MEASUREMENT DEVICES  
3 AND COMPONENTS THEREOF  
4 INVESTIGATION NO.: 337-TA-1276  
5 HEARING DATE: June 7, 2022  
6 LOCATION: Washington, D.C. - Remote  
7 NATURE OF HEARING: Evidentiary Hearing

8 I hereby certify that the foregoing/attached  
9 transcript is a true, correct and complete record of the  
10 above-referenced proceedings of the U.S. International Trade  
11 Commission.  
12 Date: June 7, 2022  
13 Signed:   
14 ss//  
15 Signature of the Contractor or the Authorized Contractor's  
16 Representative

17 I hereby certify that I am not the court reporter  
18 and that I have proofread the above-referenced transcript of  
19 the proceedings of the U.S. International Trade Commission  
20 against the aforementioned court reporter's notes and  
21 recordings for accuracy in transcription in the spelling,  
22 hyphenation, punctuation and speaker identification and did  
23 not make any changes of a substantive nature. The  
24 foregoing/attached transcript is a true, correct and  
25 complete transcription of the proceedings.  
Signed:  
ss// 

26 I hereby certify that I reported the  
27 above-referenced proceedings of the U.S. International Trade  
28 Commission and caused to be prepared from my record media  
29 and notes of the proceedings a true, correct and complete  
30 verbatim recording of the proceedings.  
Signed:  
ss// 

# UNITED STATES INTERNATIONAL TRADE COMMISSION

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In the Matter of

Investigation No.

CERTAIN LIGHT-BASED PHYSIOLOGICAL

337-TA-1276

MEASUREMENT DEVICES AND COMPONENTS

THEREOF

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REVISED AND CORRECTED TRANSCRIPT

OPEN/CLOSED SESSIONS

Pages: 597 through 861

Place: Washington, D.C.

Date: June 8, 2022

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**Appx40691**

1 UNITED STATES INTERNATIONAL TRADE COMMISSION

2 Washington, D.C.

3 Before the Honorable Monica Bhattacharyya

4 Administrative Law Judge

5

6 -----x

7 In the Matter of Investigation No.

8

9 CERTAIN LIGHT-BASED PHYSIOLOGICAL 337-TA-1276

10 MEASUREMENT DEVICES AND COMPONENTS

11 THEREOF

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15 EVIDENTIARY HEARING

16 Wednesday, June 8, 2022

17 Volume III

18

19

20 The parties met via remote videoconferencing  
21 pursuant to notice of the Administrative Law Judge at 9:30  
22 a.m. Eastern.

23

24

25 Reported by: Linda S. Kinkade RDR CRR RMR RPR CSR

1 A P P E A R A N C E S:

2 [All parties appeared via remote videoconferencing and/or  
3 telephonically.]

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25 CONTINUED ON FOLLOWING PAGE

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25 CONTINUED ON FOLLOWING PAGE

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25 CONTINUED ON FOLLOWING PAGE



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25 CONTINUED ON FOLLOWING PAGE

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17 \*\*\* Index appears at end of transcript \*\*\*

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1 O P E N S E S S I O N

2

3 MR. CLAASSEN: Good morning, Your Honor. This is  
4 Brian Claassen on behalf of Masimo. For the next witness  
5 Masimo calls Dr. Vijay Madisetti.

6 THE WITNESS: Good morning, Your Honor.

7 JUDGE BHATTACHARYYA: Good morning,  
8 Dr. Madisetti. Do you understand you're under an obligation  
9 to testify truthfully today?

10 THE WITNESS: I do.

11 VIJAY MADISETTI,

12 having been first duly sworn and/or affirmed  
13 on his oath, was thereafter examined and testified as  
14 follows:

15 DIRECT EXAMINATION

16 BY MR. CLAASSEN:

17 Q. Good morning, Dr. Madisetti.

18 A. Good morning, sir.

19 Q. Please introduce yourself and spell your last  
20 name for the court reporter.

21 A. My name is Vijay Madisetti. My last name is  
22 spelled M-A-D-I-S-E-T-T-I.

23 Q. Did you prepare demonstrative slides regarding  
24 your analysis in this case?

25 A. Yes, I did.

1 Q. Let's pull up CDX-11, please.

2 Turning to the next slide, slide 2,

3 Dr. Madisetti, will you explain your background?

4 A. Yes. I'm a full professor at Georgia Tech in the  
5 Colleges of Engineering and Computer Science. I have a  
6 Ph.D. from the University of California at Berkeley in  
7 electrical engineering and computer science, and my CV is  
8 shown attached as Exhibit 329.

9 Q. Dr. Madisetti, is your CV Exhibit 329 current?

10 A. Yes.

11 Q. Turning to the next slide, Dr. Madisetti, could  
12 you tell me your assignment in this case? Excuse me. Let's  
13 go to slide 4, please.

14 Dr. Madisetti, can you explain your background  
15 with respect to -- with respect to publications and books  
16 that you've written?

17 A. Yes. In the area of this investigation I've been  
18 working, teaching, researching, and consulting in the area  
19 of signal processing, chip design, software design, for over  
20 30 years.

21 These are some of the books that I've written,  
22 starting back in the '90s until last year, I've been focused  
23 on the areas of signal crossing, chip design, and software,  
24 and along the way I've also taught many courses and done  
25 research in these areas.

1 Q. Turning to the next slide, Dr. Madisetti, can you  
2 describe for the ALJ what technical articles you've written  
3 relating to biological signal processing?

4 A. Yes. Over the past 30 years I've authored many  
5 papers in technologies such as filters, cancellers,  
6 noise-reduction techniques, adaptive digital filters, and  
7 also, for example, on the right, pulse signals, pulse  
8 oximetry is a special case of this particular general  
9 problem. I've also designed a pulse oximeter.

10 MR. CLAASSEN: Your Honor, at this time Masimo  
11 moves to admit Dr. Madisetti as a technical expert in the  
12 field of physiological monitoring technologies.

13 JUDGE BHATTACHARYYA: Any objection?

14 MS. FRAZIER: There is, Your Honor. No objection  
15 to Dr. Madisetti being admitted as an expert, but we would  
16 request that it be in the areas of expertise he recited --  
17 signal processing, chip design, and software.

18 MR. CLAASSEN: Your Honor --

19 JUDGE BHATTACHARYYA: Mr. Claassen, is that  
20 acceptable to you?

21 MR. CLAASSEN: Your Honor, Dr. Madisetti has  
22 rendered opinions regarding physiological monitoring  
23 technologies. He has explained his technical articles  
24 related to this area and his design of pulse oximeters.

25 Masimo would like to have him admitted in the

1 objection to that.

2 JUDGE BHATTACHARYYA: All right. Thank you.

3 Let's take a quick break.

4 (Whereupon, the proceedings recessed at 11:36  
5 a.m.)

6 (In session at 11:38 a.m.)

7 JUDGE BHATTACHARYYA: We're back on the public  
8 record.

9 Based on the testimony and arguments I've just  
10 heard, the objection is overruled. Dr. Madisetti will be  
11 admitted as an expert in the field of physiological  
12 monitoring technologies.

13 Counsel for Apple can explore the extent of his  
14 expertise on cross-examination.

15 MS. FRAZIER: Thank you, Your Honor.

16 MR. CLAASSEN: Your Honor, I'd like to clarify  
17 that the time was charged to Apple with respect to the voir  
18 dire and the objection.

19 JUDGE BHATTACHARYYA: I understand the parties  
20 have an agreement regarding how to charge time. I ask that  
21 the parties discuss it, and, if there's a dispute, you can  
22 raise it before me.

23 MR. CLAASSEN: Thank you, Your Honor. We'll do  
24 that.

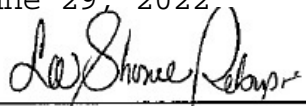
25 BY MR. CLAASSEN:

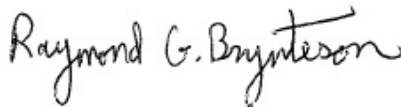
**APPX40795-40798**  
**ENTIRELY REDACTED**


**APPX40803-40822**  
**ENTIRELY REDACTED**



1 C E R T I F I C A T E  
2 TITLE: CERTAIN LIGHT-BASED PHYSIOLOGICAL MEASUREMENT DEVICES  
3 AND COMPONENTS THEREOF  
4 INVESTIGATION NO.: 337-TA-1276  
5 HEARING DATE: June 8, 2022  
6 LOCATION: Washington, D.C. - Remote  
7 NATURE OF HEARING: Evidentiary Hearing

8 I hereby certify that the foregoing/attached  
9 transcript is a true, correct and complete record of the  
10 above-referenced proceedings of the U.S. International Trade  
11 Commission.  
12 Date: June 29, 2022  
13 Signed:   
14 ss//  
15 Signature of the Contractor or the Authorized Contractor's  
16 Representative

17 I hereby certify that I am not the court reporter  
18 and that I have proofread the above-referenced transcript of  
19 the proceedings of the U.S. International Trade Commission  
20 against the aforementioned court reporter's notes and  
21 recordings for accuracy in transcription in the spelling,  
22 hyphenation, punctuation and speaker identification and did  
23 not make any changes of a substantive nature. The  
24 foregoing/attached transcript is a true, correct and  
25 complete transcription of the proceedings.  
Signed:  
ss// 

26 I hereby certify that I reported the  
27 above-referenced proceedings of the U.S. International Trade  
28 Commission and caused to be prepared from my record media  
29 and notes of the proceedings a true, correct and complete  
30 verbatim recording of the proceedings.  
Signed:  
ss// 

# UNITED STATES INTERNATIONAL TRADE COMMISSION

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In the Matter of

Investigation No.

CERTAIN LIGHT-BASED PHYSIOLOGICAL

337-TA-1276

MEASUREMENT DEVICES AND COMPONENTS

THEREOF

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## OPEN/CLOSED SESSIONS

Pages: 862 through 1167

Place: Washington, D.C.

Date: June 9, 2022

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**Appx40957**

1 UNITED STATES INTERNATIONAL TRADE COMMISSION

2 Washington, D.C.

3 Before the Honorable Monica Bhattacharyya

4 Administrative Law Judge

5

6 -----x

7 In the Matter of Investigation No.

8

9 CERTAIN LIGHT-BASED PHYSIOLOGICAL 337-TA-1276

10 MEASUREMENT DEVICES AND COMPONENTS

11 THEREOF

12 -----x

13

14

15 EVIDENTIARY HEARING

16 Thursday, June 9, 2022

17 Volume IV

18

19

20 The parties met via remote videoconferencing  
21 pursuant to notice of the Administrative Law Judge at 9:30  
22 a.m. Eastern.

23

24

25 Reported by: Linda S. Kinkade RDR CRR RMR RPR CSR

**Appx40958**

Heritage Reporting Corporation  
(202) 628-4888

1 A P P E A R A N C E S:

2 [All parties appeared via remote videoconferencing and/or  
3 telephonically.]

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17 \*\*\* Index appears at end of transcript \*\*\*

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1 O P E N S E S S I O N

2

3 MR. MUELLER: Your Honor, as our next witness we  
4 call Dr. Ueyn Block, and Ms. Frazier will do the  
5 examination.

6 MS. FRAZIER: Dr. Mehra, assuming it's okay with  
7 Her Honor, you are free to go.

8 JUDGE BHATTACHARYYA: Yes. Thank you for your  
9 time.

10 THE WITNESS: Thanks. Sounds good.

11 JUDGE BHATTACHARYYA: Good morning, Dr. Block.

12 THE WITNESS: Good morning.

13 JUDGE BHATTACHARYYA: Do you understand that you  
14 have an obligation to tell the truth here today?

15 THE WITNESS: Yes.

16 UEYN BLOCK,

17 having been first duly sworn and/or affirmed  
18 on his oath, was thereafter examined and testified as  
19 follows:

20 JUDGE BHATTACHARYYA: Thank you.

21 You may proceed.

22 DIRECT EXAMINATION

23 BY MS. FRAZIER:

24 Q. Good morning, Dr. Block.

25 A. Good morning.

1 Q. Could you please introduce yourself to Her Honor?

2 A. Absolutely. My name is Ueyn Block, and I work at  
3 Apple.

4 Q. What is your educational background?

5 A. I have a Bachelor's degree in physics and  
6 mathematics and then got a Master's and a Ph.D. degree in  
7 applied physics at Stanford University.

8 Q. What did you do after you defended your  
9 dissertation at Stanford?

10 A. I went from Stanford to a startup company working  
11 on noninvasive biomedical optics devices and stayed there  
12 for about six years.

13 Q. And after that what did you do?

14 A. I pursued a job at Apple and went directly from  
15 that company to Apple.

16 Q. When did you join Apple?

17 A. I joined Apple in March of 2013.

18 Q. Why were you interested in working at Apple?

19 A. Basically I've been a longtime appreciator of the  
20 company since using products dating back all the way to the  
21 '80s, and for me it was some kind of a dream job. I had  
22 actually tried to get a job there straight out of graduate  
23 school but didn't have the right qualifications at that  
24 time, so I eventually got there.

25 Q. Dr. Block, what products have you worked on

**APPX40996-40999**  
**ENTIRELY REDACTED**

1 O P E N S E S S I O N

2

3 MR. MUELLER: Your Honor, for our next witness we  
4 call Dr. Steve Waydo, and Ms. Garcia will do the  
5 examination, Nina Garcia.

6 MS. GARCIA: Good morning, Your Honor. Nina  
7 Garcia for Respondent Apple.

8 JUDGE BHATTACHARYYA: Good morning, Dr. Waydo. I  
9 believe you're on mute.

10 THE WITNESS: Good morning.

11 JUDGE BHATTACHARYYA: Welcome. Do you understand  
12 that you are under an obligation to tell the truth here  
13 today?

14 THE WITNESS: I do.

15 STEPHEN WAYDO,

16 having been first duly sworn and/or affirmed  
17 on his oath, was thereafter examined and testified as  
18 follows:

19 JUDGE BHATTACHARYYA: You may proceed, counsel.

20 DIRECT EXAMINATION

21 BY MS. GARCIA:

22 Q. Good morning, sir. Would you please introduce  
23 yourself? Where do you live? Where do you work?

24 A. My name is Stephen Waydo. I live in Saratoga,  
25 California, and I work for Apple.

1 Q. What is your current role at Apple?

2 A. I'm director of a group called HID Health.

3 Q. What is HID Health?

4 A. HID stands for human interface devices. The  
5 larger organization builds algorithms for sensors on a  
6 variety of Apple products. My team, in particular, is  
7 responsible for health algorithms primarily on the Apple  
8 Watch.

9 Q. Dr. Waydo, could you briefly describe your  
10 educational history?

11 A. Yes. I have a Bachelor's degree in aeronautics  
12 and astronautics from the University of Washington that I  
13 obtained in 2001, and a Ph.D. in control and dynamical  
14 systems from Caltech that I obtained in 2007.

15 Q. What did you do after you received your Ph.D.  
16 from Caltech?

17 A. Before and during graduate school I worked at  
18 NASA Jet Propulsion Laboratory in Pasadena, and I continued  
19 on there as a full-time employee for about six or eight  
20 months after I finished my Ph.D.

21 Q. Can you give an example of a project that you  
22 worked on at NASA Jet Propulsion Lab?

23 A. Yes. I worked on a variety of robotic heat space  
24 exploration missions. The biggest one was a mission called  
25 Deep Impact that flew out and took pictures of a comet in

**APPX41019-41026**  
**ENTIRELY REDACTED**

**APPX41029-41030**  
**ENTIRELY REDACTED**

1 O P E N S E S S I O N

2

3 JUDGE BHATTACHARYYA: We're moving to the public  
4 record.

5 THE WITNESS: Okay.

6 BY MS. SWAROOP:

7 Q. Dr. Waydo, I believe in your direct testimony you  
8 said that you wanted to join Apple because you wanted to  
9 learn from the best, correct?

10 A. Yes.

11 Q. Okay. And, Dr. Waydo, are you aware that Apple  
12 has hired individuals from Masimo?

13 A. Yes.

14 Q. You know Mike O'Reilly, correct?

15 A. I do.

16 Q. You worked with Mike O'Reilly, correct?

17 A. Yes.

18 Q. And you filed a patent application with Mike  
19 O'Reilly; isn't that correct?

20 A. It's possible. I don't know for sure.

21 Q. Okay. Let's bring up CX-1684. It's in your  
22 binder. And we'll put it up on the screen.

23 Dr. Waydo, this is a published patent application  
24 filed by Apple naming you and Michael O'Reilly among the  
25 inventors; isn't that right?



1 A. Yes.

2 Q. Dr. Waydo, in your direct testimony you discussed  
3 the heart rate sensing feature of the Series 0 watch; isn't  
4 that right?

5 A. Yes.

6 Q. Okay. And that watch involved a heart rate  
7 measurement, correct?

8 A. Yes.

9 Q. Okay. And the measurement of oxygen saturation  
10 is a more difficult measurement than the heart rate  
11 measurement, correct?

12 A. It's different for sure.

13 Q. It's more difficult, isn't it, Dr. Waydo?

14 A. It's very different. It solves a different set  
15 of problems. I don't know that I would characterize it as  
16 more difficult.

17 Q. Okay. Let's go to your deposition, which is in  
18 your binder, and we'll take a look at pages -- page 163,  
19 line 15, to 164, line 3.

20 A. Can you tell me where in my binder I can find  
21 that?

22 Q. It should be in your binder, if there's a tab  
23 there, I believe it's CX-298C.

24 A. Okay. And then what pages?

25 Q. Page 164 -- sorry -- page 163, line 15, to 164,

1 line 3, and I have it up on the screen as well.

2 A. Okay.

3 Q. And the question was from your own counsel:

4 What was your reaction to receiving the  
5 assignment of helping develop the blood oxygen feature for  
6 the Apple Watch?

7 And your answer:

8 I was both excited and, I'd say, intimidated.  
9 It's a more difficult measurement than the heart rate  
10 measurement, and, however, embarking on a new sensing  
11 development project is always exciting and quite a ride. So  
12 I was looking forward to it.

13 Were you asked that question and did you give  
14 that answer at your deposition, Dr. Waydo?

15 A. Yes.

16 Q. Okay. So you would agree, then, that oxygen  
17 saturation is a more difficult measurement than heart rate  
18 measurement, correct?

19 A. It depends very much on the context, but in some  
20 contexts, yes.

21 Q. Okay. And, in fact, it was extremely challenging  
22 to develop the blood oxygen feature in the Apple Watch,  
23 correct?

24 A. Yes.

25 Q. Now you've been involved in assessing the

1 accuracy of the blood oxygen feature of the Apple Watch,  
2 correct?

3 A. Not in a hands-on way, but I reviewed the data.

4 Q. You understand when talking about accuracy that  
5 there's a difference between sensitivity on the one hand and  
6 specificity on the other hand, correct?

7 A. Yes.

8 Q. And let's talk first about sensitivity.

9 An Apple Watch that detects everyone who has a  
10 particular medical condition would be an example of a highly  
11 sensitive device, correct?

12 A. Yes.

13 Q. Okay. And that's different from specificity,  
14 correct?

15 A. That's correct.

16 Q. Okay. An Apple Watch that detects medical  
17 conditions in people who do not actually have that medical  
18 condition would be an example of a device with low  
19 specificity, correct?

20 A. Yes.

21 Q. Okay. And in your direct today you didn't  
22 present any information on false alarms, that is, people who  
23 went to seek out medical care or thought something was wrong  
24 with them based on something from the Apple Watch but had no  
25 reason to do so, correct?

1 as its next witness Brian Land.

2 JUDGE BHATTACHARYYA: Good morning, Mr. Land. Do  
3 you understand you're under an obligation to tell the truth  
4 in your testimony today?

5 THE WITNESS: Yes.

6 BRIAN LAND,  
7 having been first duly sworn and/or affirmed  
8 on his oath, was thereafter examined and testified as  
9 follows:

10 JUDGE BHATTACHARYYA: Thank you.

11 MR. MUELLER: May I proceed, Your Honor?

12 JUDGE BHATTACHARYYA: Yes, please.

13 DIRECT EXAMINATION

14 BY MR. MUELLER:

15 Q. Good morning, Mr. Land. Could you please  
16 introduce yourself to Her Honor?

17 A. Yes. My name is Brian Land. I live in Woodside,  
18 California, and I work at Apple.

19 Q. Sir, could you please describe your educational  
20 background starting with college?

21 A. Yes. I have a Bachelor's of Science in Material  
22 Science and Engineering from Cornell University, and I have  
23 a Master of Science in Material Science and Engineering from  
24 Stanford University.

25 Q. Mr. Land, what year did you earn your Master's

1 from Stanford?

2 A. 1992.

3 Q. And what did you do next?

4 A. I went for work -- to work at a startup company  
5 that designed sensors, specifically gyroscopes and  
6 applications that integrated sensors and gyroscopes.

7 Q. What was the name of that company?

8 A. It was called Gyration.

9 Q. For how long did you work at Gyration?

10 A. I worked there 12 years.

11 Q. What type of work did you do in that time?

12 A. It was a small company. It was a startup, so I  
13 had to wear a lot of hats. But the main tasks were  
14 designing gyroscopes, designing test equipment, and  
15 manufacturing equipment to build and test gyroscopes, and  
16 then designing applications that integrated the gyroscopes  
17 into bigger systems that we could try to sell to customers.

18 Q. Sir, what did you find interesting about working  
19 on these types of sensors?

20 A. Well, I really like sensors because they require  
21 engineering knowledge across multiple domains, examples  
22 being electrical, mechanical, physics. And the best design  
23 requires really an understanding of all of them, and so I  
24 got to apply many engineering skills. And I also  
25 particularly like sensors because they interface with the

1 world at large, they tell us something about the outside  
2 world, and the world is complex, and, because it's complex,  
3 it's a challenging engineering problem.

4 Q. Now, sir, when did you leave Gyration to go to  
5 work at Apple?

6 A. It was spring of 2005.

7 Q. And why did you make the decision to join Apple?

8 A. Gyration was -- I really enjoyed working there,  
9 but it was a small company and the products that we sold  
10 were sold in modest numbers, and we did excellent  
11 engineering work, we made great products, but I felt like I  
12 had an opportunity to make a bigger impact at a company like  
13 Apple, which is, you know, has been a premier company in the  
14 electronics and computer space for many years.

15 Q. What is your current position at Apple?

16 A. It's -- my title is distinguished engineer.

17 Q. Sir, what does it mean to be a distinguished  
18 engineer at Apple?

19 A. It's a title and a job level that is granted upon  
20 engineers and technical people at Apple who have achieved  
21 technical excellence during their time at Apple in  
22 developing Apple products.

23 Q. And, Mr. Land, in your responsibilities as a  
24 distinguished engineer today, which group do you work with  
25 at Apple?

1           A.    I lead a hardware development team called Health  
2   Sensing Hardware.

3           Q.    How many engineers work under your supervision?

4           A.    It's about 55 or 56.

5           Q.    Which Apple products does the Health Sensing  
6   Hardware Group that you head up contribute to, which Apple  
7   product in the market today?

8           A.    It's primarily the Apple Watch, the health  
9   sensors for the Apple Watch.

10          Q.    Now I want to just briefly rewind to when you  
11   joined the company and the period between when you joined  
12   Apple and when you began working on Apple Watch.

13                Do you have that time period in mind?

14          A.    Yes.

15          Q.    In that time period, sir, what were some of the  
16   other products that you worked on?

17          A.    I've worked on many types of Apple products.  I  
18   worked on the first iPhone.  I've worked -- I developed -- I  
19   was part of the team that developed the touchscreen for the  
20   first iPhone.  I was part of the team that developed the  
21   touchscreen for the first iPad.

22                I've also worked on optical sensors, such as an  
23   optical proximity sensor, which would be used in a phone to  
24   turn the screen off when you bring it near your head so your  
25   cheek doesn't push a button by mistake.

1 I've also worked on ambient light sensors, which  
2 look out into the room to determine how bright the room is,  
3 or if you're outdoors and can adjust the screen brightness  
4 to a level that's appropriate for the room brightness.

5 Q. Fair to say, you and your colleagues at Apple had  
6 worked on many different types of sensors before the Apple  
7 Watch?

8 A. Yes.

9 Q. Let me take you to the Apple Watch. The very  
10 first Apple Watch was called the Series 0; is that right,  
11 sir?

12 A. Yes, that's correct.

13 Q. And that was released to the general public in  
14 April of 2015. Do I have that right?

15 MR. RE: Leading, Your Honor.

16 A. Yes, I think that's approximately correct. It  
17 was in the spring of 2015.

18 JUDGE BHATTACHARYYA: I didn't rule on the  
19 objection.

20 Mr. Mueller, can you rephrase so it's not  
21 leading.

22 MR. MUELLER: Sure.

23 Q. When was the first Apple Watch, the Series 0,  
24 released to the general public?

25 A. It was the spring of 2015. I don't remember the



**APPX41058-41062**  
**ENTIRELY REDACTED**

**APPX41077-41080**  
**ENTIRELY REDACTED**

1 O P E N S E S S I O N

2

3 JUDGE BHATTACHARYYA: Welcome, Dr. Mannheimer.

4 Do you understand that you are under an  
5 obligation to tell the truth in your testimony today?

6 THE WITNESS: I do.

7 PAUL MANNHEIMER,

8 having been first duly sworn and/or affirmed  
9 on their oath, was thereafter examined and testified as  
10 follows:

11 JUDGE BHATTACHARYYA: Go ahead, Mr. Mueller.

12 MR. MUELLER: It looks like we may have lost the  
13 witness. There we go. We're ready to proceed.

14 JUDGE BHATTACHARYYA: Sounds good.

15 DIRECT EXAMINATION

16 BY MR. MUELLER:

17 Q. Good afternoon, Dr. Mannheimer. Can you please  
18 introduce yourself to Her Honor?

19 A. Yes. Your Honor, my name is Paul Mannheimer. I  
20 live in Los Altos and I work at Apple.

21 Q. Sir, what is your role at Apple?

22 A. I'm a sensor architect and scientist.

23 Q. What is your educational background starting with  
24 college?

25 A. I have my undergraduate degree in physics from

1 the University of California at Berkeley.

2 Q. Did you earn any graduate degrees over the years?

3 A. Yes. I obtained My master's degree in applied  
4 physics from Stanford University, and my Ph.D. from the  
5 University of Lubeck in Germany in biomedical engineering.

6 Q. Now when did you start to work for Apple?

7 A. At the very end of 2014.

8 Q. Before you worked at Apple what were you doing?

9 A. Just prior to joining Apple I was an independent  
10 consultant with my own consulting practice.

11 Q. And before serving as an independent consultant,  
12 did you work at another company?

13 A. Yes, I did. I worked at Nellcor. Although at  
14 the time they were Covidien, when I left, but it was Nellcor  
15 and then a variety of flavors of Nellcor.

16 Q. Dr. Mannheimer, for how long did you work at  
17 Nellcor?

18 A. I believe it was around 21 years.

19 Q. And would that be from around 1987 to 2008?

20 A. Yes, that's correct.

21 Q. What did you do in those 20-plus years at  
22 Nellcor?

23 A. I developed pulse oximetry sensors, some  
24 monitoring techniques, alarm handling techniques, I did  
25 clinical studies, a variety of roles.

**APPX41094-41097**  
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**APPX41108-41110**  
**ENTIRELY REDACTED**

1 O P E N S E S S I O N

2

3 AFTERNOON SESSION

4 (In session at 2:00 p.m.)

5 JUDGE BHATTACHARYYA: We're on the public record.

6 MR. MUELLER: Thank you, Your Honor. We would  
7 like to call as our next witness Scott Cromar.

8 Hello, Mr. Cromar.

9 THE WITNESS: Good morning or good afternoon.  
10 Can you hear me and see me okay?

11 JUDGE BHATTACHARYYA: I can.

12 THE WITNESS: Okay. Great.

13 JUDGE BHATTACHARYYA: Do you understand that  
14 you're under an obligation to tell the truth here today?

15 THE WITNESS: Yes.

16 SCOTT CROMAR,  
17 having been first duly sworn and/or affirmed  
18 on his oath, was thereafter examined and testified as  
19 follows:

20 JUDGE BHATTACHARYYA: Proceed, counsel.

21 DIRECT EXAMINATION

22 BY MR. MUELLER:

23 Q. Good afternoon, Mr. Cromar. My name is Joe  
24 Mueller, and I'd like to ask you a few questions, if I  
25 could.

1 A. Okay.

2 Q. Mr. Cromar, you are an attorney, correct?

3 A. Yes, that's correct.

4 Q. And you prosecute patents, right, sir?

5 A. Yes.

6 Q. You've prosecuted in the range of a hundred or so  
7 patents for Masimo or Cercacor, correct?

8 A. I don't know what the specific number is. That  
9 might be right. Something like that, quite a few.

10 Q. Now, sir, you're a partner at Knobbe Martens,  
11 right?

12 A. Yes, that's right.

13 Q. That's the same firm as Mr. Re and Ms. Swaroop  
14 and their colleagues, correct?

15 A. Yes.

16 Q. Now you, sir, were the prosecutor and helped  
17 primary responsibility for the prosecution of three of the  
18 patents in this investigation; is that fair?

19 A. Yes, that's right.

20 Q. The '501, '502, and '648, correct?

21 A. Correct.

22 Q. Now the original priority application for those  
23 patents was filed in 2008, right?

24 A. Are you referring to the provisionals that the  
25 patents-in-suit claim priority to?



1 Q. That's correct, sir.

2 A. I believe there were multiple provisionals, so  
3 they were -- I think they were filed in 2008 in different  
4 times in 2008.

5 Q. Now the '501, '502, and '648 were filed on  
6 September 24th of the year 2000, right? I'm sorry. 2020.  
7 I misspoke. 2020. Is that right, sir?

8 A. That's consistent with my recollection at the  
9 moment. I would have to look at the files just to confirm  
10 that that date is correct, but I believe that's correct.

11 Q. Just to make this a little easier, if we could go  
12 to tab 1 in the binder that you should have in front of you.  
13 This is your deposition from this case. You were deposed,  
14 right, sir?

15 A. Yes, I was deposed. I don't know for sure which  
16 binder you're referring to. I have a binder that says  
17 Cromar direct on it and there's also a sealed envelope.

18 Q. You can open the sealed envelope right now, sir.

19 A. Okay. Let me grab that. I was told that I  
20 should open this on camera; is that correct?

21 Q. Go right ahead.

22 A. All right. So I think, is this the binder that  
23 you're referring to?

24 Q. Yes, tab 1, please, sir. Page 108, lines 14-17.  
25 We can put these up on the screen too.

1 Question. Okay. So you filed the applications  
2 for the '501, '502, and '648 patents on the same day, that  
3 was September 24th, 2020, correct?

4 Answer. I believe that's correct.

5 Does that refresh your memory, sir?

6 A. Sorry. You got a little ahead of me. I was  
7 trying to open to the correct page. So you said it's page  
8 108?

9 Q. No -- that's right -- 108, lines 14-17, please,  
10 sir.

11 A. Okay. I'm there now.

12 Q. And you see here, you were asked whether you  
13 filed these three patents on the same day, September 24th,  
14 2020, correct?

15 A. Correct. I believe that's the correct date, but  
16 I would have to go verify that by looking at the file  
17 histories.

18 Q. Now that's 12 years after 2008, right?

19 A. Yes. You're asking for the difference between  
20 the year 2008 and the year 2020, correct?

21 Q. Twelve years, right?

22 A. That would be 12 years, that's right.

23 Q. Now you couldn't identify at your deposition any  
24 reason why, for example, the application for the '501 patent  
25 could not have been filed earlier than September of 2020,

1 correct?

2 A. I don't know that that's correct. Can I refresh  
3 my recollection, or do you have something that can remind  
4 me?

5 Q. Absolutely. Let's go to page 90 in your  
6 deposition, lines 2-11.

7 Question. Sitting here today, you cannot  
8 identify any reason why the application for the '501 patent  
9 could not have been filed earlier than September 2020,  
10 correct?

11 Yeah. Again, I -- I haven't formed an opinion on  
12 that, and I don't feel comfortable doing so as we sit here.

13 Were you asked that question and did you give  
14 that answer?

15 A. Yes, that's correct. I believe my answer to the  
16 question was that I haven't formed an opinion on it, and,  
17 you know, at the time I hadn't formed an opinion on it.

18 Q. Let's pull up CX-1287. This is a press release  
19 for the release of the Apple Watch Series 6. Let me just  
20 focus you on the date.

21 Do you see September 15th, 2020?

22 A. Yeah, I see that on the screen.

23 Q. That's nine days before you filed the  
24 applications that led to the '501, '502, and '648 patents,  
25 correct?

1           A.    Just to confirm, I understand the question  
2   correctly, you're asking for the difference between  
3   September 15th, 2020, and September 24th, 2020?

4           Q.    Nine days, right?

5           A.    Yes, there's -- that would be nine days, that's  
6   right.

7           Q.    Now over the course of the prosecution of these  
8   three patents, the '501, '502, and '648, you had access to  
9   confidential teardowns of the Apple Series 6 watch, correct?

10          A.    I am not sure -- the question sounds kind of like  
11   it's potentially getting into privileged information, and  
12   I'm not sure if I can answer.

13          Q.    Let me take you to your deposition, at page 245,  
14   lines 12-18.

15                Question. Did you see those nonpublic teardowns  
16   of the Apple Watch Series 6 during prosecution of the '501,  
17   '502, and '648 patents?

18                The Witness: Yes, I think so.

19                Were you asked that question and did you give  
20   that answer?

21          A.    I'm getting to that page. I see that, yes, I  
22   believe that's correct.

23          Q.    Now at your deposition you did not answer because  
24   you said you could not answer without revealing privileged  
25   information the following question:

1           You drafted the claims of the '501 patent  
2     application to cover Apple Watch products.

3           At your deposition you were unable to answer that  
4     question without revealing privileged information, true?

5           MR. RE: Objection, Your Honor, again, seeing an  
6     adverse inference from the assertion of the privilege which  
7     is wholly improper and unethical.

8           MR. MUELLER: It's neither improper nor  
9     unethical, Your Honor. Right now I'm not asking for any  
10    adverse inference; I'm asking for the facts.

11          MR. RE: No, the privilege has been asserted. I  
12    don't see why you're asking questions where you know the  
13    privilege has been asserted.

14          MR. MUELLER: Your Honor, what I asked was, you  
15    couldn't answer the question on the grounds that it would  
16    reveal privileged information. This is precisely the same  
17    question we asked an earlier witness in the hearing,  
18    Your Honor.

19          MR. RE: Sounds like we're in agreement.

20          MR. MUELLER: That was not a sustained objection.  
21    The question was permitted. I'm asking the exact same form  
22    of the question now.

23          JUDGE BHATTACHARYYA: I'll allow the question.

24          Mr. Re, to the extent you want to argue, there  
25    shouldn't be any adverse inference.

1 MR. RE: I'm sorry. I didn't hear Your Honor.  
2 There was some noise from another room.

3 JUDGE BHATTACHARYYA: To the extent you want to  
4 argue that there should not be any inference, adverse  
5 inference from that testimony, you're free to make that  
6 argument, but I'm not going to sustain the objection.

7 BY MR. MUELLER:

8 Q. Mr. Cromar, I want to repeat the question just to  
9 make sure you have it fresh in mind.

10 At your deposition you didn't think you could  
11 answer without revealing privileged information following  
12 question: You drafted the claims of the '501 patent  
13 application to cover Apple Watch products.

14 You were asked that question and you said you  
15 couldn't answer it without revealing privileged information,  
16 true?

17 A. Did you want to point me to part of the  
18 deposition transcript so I can confirm that that's accurate?

19 Q. Certainly. Let's go to page 179, lines 13-20.

20 Question. You drafted the claims of the '501  
21 patent application to cover Apple Watch products, correct?

22 I don't think I can answer that without revealing  
23 privileged information.

24 Were you asked that question and did you give  
25 that answer?

1           A.     That seems correct. Like I said earlier, it  
2     seems like the question is asking for potentially, you know,  
3     protected information, privileged information, so I'm not  
4     sure that I can answer it.

5           Q.     Thank you, sir.

6                   MR. MUELLER: I pass the witness.

7                               CROSS-EXAMINATION

8     BY MR. RE:

9           Q.     Good afternoon or good morning for you,  
10    Mr. Cromar.

11                   You were asked about your awareness of the Apple  
12    Watch during prosecution. I wonder if you can tell me if  
13    there's anything else you can recall with regard to Apple  
14    during the prosecution of these applications that  
15    Mr. Mueller raised with you.

16                   MR. MUELLER: Your Honor, I'm just going to  
17    object to the question to the extent that it elicits  
18    information that we were shielded from receiving on the  
19    basis of a privilege assertion both at his deposition and  
20    just now.

21                   If it's going to be something different, I have  
22    no objection, but I do object if we're now going to hear  
23    facts that were not given at his deposition and were not  
24    given when I just asked him questions a few minutes ago.

25                   MR. RE: Of course.

1 Q. Only stuff that you know is public and doesn't  
2 involve an attorney-client communication.

3 MR. MUELLER: I'm not sure what that question is  
4 referring to, Your Honor, so I object to the form of the  
5 question.

6 JUDGE BHATTACHARYYA: I'm not going to sustain  
7 the objection at this time. Why don't we go ahead and see  
8 what the testimony is.

9 A. Just to confirm that I understand the question,  
10 you're talking about around the time of the prosecution of  
11 the patents-in-suit?

12 Q. Yes. Yes, and what was happening.

13 A. Sure. I recall that around that time Apple was  
14 producing quite a bit of prior art through IPRs and District  
15 Court litigation, and that that was information that we  
16 wanted to make sure we took into consideration and filed an  
17 IDS, for example, Masimo was developing their watch around  
18 that time. Prosecution of other patent applications was  
19 going on. Those are what I can think of at the moment.

20 Q. Are you suggesting you used -- you sent to the  
21 Patent Office IPR materials generated by Apple?

22 A. Yeah, that's right. I'd have to go look at the  
23 file just to confirm exactly which materials or which IPRs  
24 had, you know, started at that point, but that was  
25 definitely information that was being filed in IDSes to the



1 Patent Office during that time and that we were receiving.

2 Q. One other area I want to get to. Mr. Mueller  
3 suggested or made some comment about a 12-year period. Did  
4 you remember that?

5 A. Yes.

6 Q. And he is talking about the 12-year period  
7 between the filing of some provisional applications in 2008  
8 and the filing of some patents in 2020. Do you remember  
9 that? That's the 12-year period we're talking about?

10 A. Yes, I remember.

11 Q. And can you, very briefly, just describe for  
12 Your Honor what was happening with regard to the patent  
13 prosecution activity in this family of patents in that  
14 12-year time frame?

15 A. In this family there was active prosecution  
16 through that time period. I believe there were over 30  
17 applications or continuations filed and actively prosecuted  
18 during that time period.

19 Q. Was there any sort of delay on your part in  
20 prosecuting those patents in that period?

21 A. No.

22 MR. RE: I have no further questions.

23 Thank you, Mr. Cromar.

24 MR. MUELLER: Very briefly, Your Honor.

25 JUDGE BHATTACHARYYA: Yes, please proceed.

1 REDIRECT EXAMINATION

2 BY MR. MUELLER:

3 Q. I'm going to pull up a slide from my opening  
4 statement for just a moment, and this shows some of the  
5 prosecution activities for this family of patents.

6 This is RDX-1.16. Here we have the timeline for  
7 the '501, '502, and '648 patents. Do you see that, sir?

8 A. Yes. Excuse me. Yes, I see that.

9 Q. And do you see in the top we have various, in  
10 blue, Apple Watch releases, Apple Watch Series 0, Series 4,  
11 Series 5, Series 6, do you see that?

12 A. Yes, I see that.

13 Q. Do you see that in each instance, in each  
14 instance, you and other folks prosecuting applications in  
15 this family on behalf of Masimo -- I'm not sure if it was  
16 just you or others as well -- filed applications after the  
17 Apple Watch models were released? Do you see that, sir?

18 A. I see the timeline and the notes on it. I don't  
19 think I could come to the conclusion that -- it seems like  
20 you're implying.

21 Q. Sir, you have no reason as you sit here right now  
22 to contest the timeline shown on this slide, correct?

23 A. No. I think I do.

24 Q. What specifically are you contesting in terms of  
25 the chronology?

1           A.   Well, there's at least a couple of things. The  
2 first one, I would say, is I see a five-year gap arrow from  
3 2008 to 2015. I'm not sure what that represents. I know  
4 that during that time period in the family there were many  
5 applications filed and being actively prosecuted. So  
6 that's, you know, that's just one example.

7           The slide also represents a 12-year delay, which  
8 I just answered a question a moment ago, I do not believe  
9 there was a delay.

10          Q.   Sir, I guess -- let me put it this way. I'm not  
11 asking you about the labeling. I'm asking you about the  
12 chronology.

13           You do not contest, do you, sir, that the dates  
14 shown for Masimo filing applications in this family on this  
15 slide are correct.

16          A.   Well, I don't know if this represents all the  
17 filings in family. It appears to me it's missing some of  
18 the filings. So to that extent I think it would be a  
19 misrepresentation.

20           MR. MUELLER: I have nothing further for this  
21 witness, Your Honor. I pass the witness.

22                               RECROSS-EXAMINATION

23 BY MR. RE:

24          Q.   Please explain what you mean why it is a  
25 misrepresentation.

1 If we can keep that slide up. Where did it go?

2 MR. MUELLER: We can pull it back up.

3 MR. RE: We'll do it from here.

4 Q. Before we begin, Mr. Cromar, have you ever seen  
5 this slide before?

6 A. No, I have not.

7 Q. Okay. You didn't like the label "gap." Can you  
8 please explain why you didn't like the five-year gap label?

9 A. Yes. Like I said, I think during that time  
10 period there were a dozen applications being actively  
11 prosecuted in this family, including continuation filings  
12 during that time period.

13 Q. With regard to the 12-year delay, you said there  
14 was no delay, but what did you mean why there's no delay?

15 A. Well, I don't know what delay means in this  
16 context, and if it's referring to a delay that I may have  
17 done, I don't recall any delays so -- and, you know, like I  
18 mentioned earlier, I believe through that 12-year time  
19 period there were more than 30 applications being  
20 prosecuted, and I only see a small fraction of those  
21 represented on the slide. It only mentions one, two --  
22 let's see -- plus four plus two, so that's, you know, seven  
23 applications. I know that there were more than 30. So I  
24 don't know -- the delay seems like a misrepresentation and  
25 this slide doesn't represent the family very well.

1 Q. And in the misrepresentation, is there some sort  
2 of correlation, we'll call it, between when you file  
3 applications in those 30 cases or so you mentioned and the  
4 releases of various Apple Watches?

5 A. I don't think so, especially because a huge  
6 portion of the prosecution happened before any Apple Watch  
7 was released. Like I said, in that early period there were  
8 many applications, so I'm not sure how there could be a  
9 correlation.

10 Q. Okay.

11 MR. RE: I have no further questions, Your Honor.

12 MR. MUELLER: May I ask just one, Your Honor?

13 JUDGE BHATTACHARYYA: Yes.

14 REDIRECT EXAMINATION

15 BY MR. MUELLER:

16 Q. You referred to or Mr. Re referred to  
17 misrepresentations. Sir, the application filing dates are a  
18 public record, correct?

19 A. I believe that's correct. All of the  
20 applications in the family were publicly -- they were  
21 published and prosecuted in public.

22 MR. MUELLER: Nothing further, Your Honor.

23 MR. RE: If I can have one follow-up.

24 BY MR. RE:

25 Q. Your suggestion of misleading, just so I

1 THE WITNESS: I do.

2 MAJID SARRAFZADEH,

3 having been first duly sworn and/or affirmed  
4 on his oath, was thereafter examined and testified as  
5 follows:

6 JUDGE BHATTACHARYYA: Thank you. You may go  
7 ahead. I think you're on mute, though.

8 MR. SELWYN: Can you hear me now?

9 JUDGE BHATTACHARYYA: Yes, perfectly.

10 MR. SELWYN: Thank you. May I proceed,  
11 Your Honor?

12 JUDGE BHATTACHARYYA: Yes.

13 DIRECT EXAMINATION

14 BY MR. SELWYN:

15 Q. Good afternoon, sir. Could you please introduce  
16 yourself?

17 A. I'm Majid Sarrafzadeh. I work and live in  
18 Southern California.

19 Q. Have you prepared a set of slides to present with  
20 your testimony today?

21 A. Yes, I have.

22 Q. Can we have RDX-7-2?

23 Would you please describe your educational  
24 background?

25 A. Certainly. I have received my Bachelor of

**APPX41217-41221**  
**ENTIRELY REDACTED**

1 JUDGE BHATTACHARYYA: That's fine.

2 MR. RAWSON: Dr. Rowe, I just sent you an email  
3 with that exhibit.

4 JUDGE BHATTACHARYYA: Dr. Rowe, you might be on  
5 mute.

6 Welcome, Dr. Rowe. Do you understand that you  
7 are under an obligation to testify truthfully here today?

8 THE WITNESS: I do.

9 ROBERT ROWE,  
10 having been first duly sworn and/or affirmed  
11 on his oath, was thereafter examined and testified as  
12 follows:

13 JUDGE BHATTACHARYYA: Thank you. You may  
14 proceed.

15 MS. VREELAND: Thank you.

16 DIRECT EXAMINATION

17 BY MS. VREELAND:

18 Q. Dr. Rowe, if you could begin by introducing  
19 yourself to Her Honor.

20 A. Yes, Your Honor. I'm Robert Rowe.

21 Q. Dr. Rowe, I'd like to focus my questions today on  
22 the Lumidigm patent, but before I do, could you briefly  
23 describe your personal background beginning with your  
24 educational history?

25 A. Sure. I have a undergraduate degree in



1 mechanical engineering from Kettering University, used to be  
2 called General Motors Institute.

3 After receiving the mechanical engineering  
4 degree, I went on to University of Arizona, where I attained  
5 a Ph.D. in optics with a primary focus on medical imaging,  
6 but certainly covering a whole range of optics and physics.

7 From that point, after getting the degree, I took  
8 an industrial postdoctoral appointment with Leica, the  
9 precision optics company in Switzerland.

10 After that I returned to the United States and  
11 had another postdoctoral appointment with Sandia National  
12 Laboratories. From there I became familiar with a very,  
13 very recent startup that was developing medical measurement  
14 technology for measuring glucose and other analytes,  
15 noninvasively, optically. So I joined that company. It was  
16 called Rio Grande Medical Technology, and later became  
17 InLight Solutions.

18 After working there for a number of years, I and  
19 some colleagues saw an opportunity to take that technology  
20 and use it as a basis for a spinout company developing a  
21 novel type of biometrics. That company was called Lumidigm.

22 Lumidigm was successful for a number of years as  
23 a startup, transitioning to a product-focused company. In  
24 2014 it was acquired by HID Global, which is a business unit  
25 of Assa Abloy, a public company in Sweden. And that is who

1 I'm with currently, HID Global.

2 Q. I'd like to take you backwards with a couple more  
3 questions before we turn to your Lumidigm patent.

4 Can you tell us what you were focused on at  
5 Sandia Labs when you did the postdoc there?

6 A. At Sandia there were a range of projects. The  
7 one -- one of them that wasn't classified and occupied a  
8 fair bit of my time was a spectroscopic measurement of  
9 semiconductor gases and trying to detect small amounts of  
10 water vapor and other impurities in the gas using  
11 spectroscopic techniques.

12 Q. How did you decide to join Rio Grande Medical  
13 when you completed that postdoc?

14 A. They, Rio Grande, had a very close working  
15 relationship with Sandia Laboratories. Some of the  
16 technology -- the original technology was shared with Sandia  
17 Laboratories, so I became familiar with Rio Grande through  
18 their collaboration, and just -- it just seemed like a  
19 fabulous opportunity to join them.

20 Q. Can you tell us about a few of the products you  
21 worked on when you were at Rio Grande Medical?

22 A. Sure. The primary focus of the company was  
23 noninvasive glucose measurement, something that a diabetic  
24 could use to measure their blood sugar without drawing  
25 blood, without poking themselves. So we designed and built

1 a variety of different spectrometers to do that.

2           Secondarily, we would measure alcohol, which both  
3 had a commercial potential, but then had some technical  
4 advantages to be able to test equipment, the spectroscopic  
5 equipment measuring alcohol.

6           And then a variety of analytes in the system that  
7 are medically important, blood gases and a variety of  
8 different analytes.

9           Q. Did Rio Grande Medical make any products that  
10 measured hemoglobin?

11          A. You know, I don't remember that. I was trying to  
12 think about that, but it wasn't primary. As I say, we  
13 measured a variety, a wide variety of analytes, but I don't  
14 recall exactly.

15          Q. If I can take you back, then, to Lumidigm. How  
16 did you -- how did you decide to found Lumidigm?

17          A. Well, technologically, what we found at Rio  
18 Grande or InLights Solutions, as it became known, is that  
19 the spectroscopic measurements that we were taking on people  
20 had a bias. From person to person they would look  
21 different, and we would have to correct for each person in  
22 order to get the medical measurements out.

23               Those lemons, if you will, became lemonade when  
24 we realized that bias from person to person, that difference  
25 from person to person, could be made into a biometric, a way

1 to identify a person and distinguish between people. So  
2 that was the technology or technological thought behind  
3 Lumidigm.

4 Q. And what was your personal role at Lumidigm?

5 A. Well, I was one of the founders of Lumidigm, and  
6 I was the Chief Technology Officer.

7 Q. Now your patent that we'll talk about in a moment  
8 mentioned something called "liveness detection." Did  
9 Lumidigm ultimately incorporate any liveness detection  
10 features into its products?

11 A. It was a very important part of what we developed  
12 all through the product family and the technology family  
13 that we developed. It was critical to be able to  
14 distinguish between real living biometric samples, fingers,  
15 for example, on humans, and those that were artificial of  
16 some kind, or even those that were dead or otherwise not  
17 living human fingers.

18 Q. And were Lumidigm's products ultimately  
19 successful?

20 A. Yes. Yeah. Yeah.

21 Q. And is Lumidigm still a standalone company?

22 A. No. It was acquired by HID in 2014.

23 Q. And what did you do after HID acquired Lumidigm?

24 A. For a couple of years I continued to be  
25 associated and developing and working within HID on the

1 Lumidigm biometrics, making further improvements there with  
2 the rest of the team, but then I transitioned into  
3 developing other biometrics, such as facial recognition, and  
4 most recently transitioned into heading up a team of data  
5 scientists working in the area of artificial intelligence,  
6 broadly, across a variety of different application spaces.

7 Q. I'd like to pull up now your '212 patent, RX-411.  
8 Can you describe -- we'll pull it on the screen and it  
9 should also be in your notebook.

10 Can you describe the work that you were doing at  
11 Lumidigm that led to the ideas described in the '212 patent?

12 A. Yeah. So the electro-optic sensors that we were  
13 designing and building for doing biometric measurements,  
14 doing spectroscopic determinations of identity and also  
15 liveness, we felt could be used for other purposes. So the  
16 '212 patent as well as other patents pertain to the extended  
17 functionality of these electro-optic sensors.

18 Q. And I see you at the very end of a very long list  
19 of inventors. What was your role in the work described in  
20 the patent?

21 A. Throughout the course of Lumidigm, including in  
22 developing this patent, I was really the key inventor, the  
23 person responsible for coming up with ideas and maturing  
24 those ideas so they could be patented.

25 In this particular case many of the concepts came

1 out of a brainstorming session that involved all the  
2 different coinventors listed on this patent, but I was -- I  
3 was the primary inventor.

4 Q. And how did you end up at the end of the list?

5 A. Yeah. Rather than the tricky process of trying  
6 to distinguish just how much each of these people  
7 contributed and ordering it according to the value of their  
8 contribution, my patent lawyers and I decided let's just  
9 alphabetize by last name.

10 Q. I'd like to ask you about some of the functions  
11 you describe in your patent, starting with column 19, lines  
12 16 to 28, which we'll put on the screen.

13 A. Okay.

14 Q. You describe here functionality that you call a  
15 hemoglobin monitor and say that it can detect spectroscopic  
16 changes that are correlated with oxygenation and hemoglobin  
17 levels in the blood.

18 How would your sensor accomplish that function?

19 A. So in the spectral range that we use, the visible  
20 and the very near infrared, hemoglobin has a very, very  
21 strong spectral signature, and we would see that spectral  
22 signature in our data.

23 Furthermore, hemoglobin has -- has two different  
24 aspects, an oxygenated hemoglobin and deoxygenated  
25 hemoglobin, both of which are strong and both of which are

1 spectrally distinct from each other.

2 So seeing the hemoglobin in the spectral data and  
3 seeing the two different forms of the hemoglobin was  
4 something that our sense was very sensitive to.

5 Q. I'd like to put up on the screen some of the  
6 figures in your patent showing your potential sensor  
7 designs, Figs. 3 through 7D. We're going to put them all up  
8 on the screen at the same time.

9 What were you illustrating in these figures?

10 A. So this is a range of embodiments of the  
11 inventions disclosed where we are showing in these figures  
12 multiple LEDs. They can be of the same wavelength. They  
13 can be of different wavelengths.

14 And we're also showing a detector or multiple  
15 detectors that can be single element. They can be  
16 multi-element. They can be one-dimensional arrays. They  
17 can be two-dimensional arrays. And then all of the  
18 different arrangement or some example arrangements of how  
19 those components can be assembled.

20 Q. I'd like to ask you just about a few of those  
21 figures, starting with we're going to put on the screen  
22 Fig. 3 and the accompanying text at 833 to 37.

23 What does your patent say about the example in  
24 Fig. 3?

25 MS. SWAROOP: Your Honor, I'd like to make an

1 objection with regard to Order No. 42.

2 Masimo filed a motion in limine with regard to  
3 Dr. Rowe's testimony, and Your Honor ruled that any  
4 questions regarding the disclosure of the Lumidigm reference  
5 must be limited to Dr. Rowe's personal and factual knowledge  
6 regarding the reference and may not seek opinion testimony  
7 regarding how one of ordinary skill in the art would  
8 interpret any particular disclosures.

9 So to the extent there's going to be testimony  
10 beyond the four corners of this patent, we object as a  
11 violation of Order No. 42.

12 MS. VREELAND: Your Honor, if I may respond.  
13 I've simply asked him what his patent discloses about  
14 Fig. 3. We've put on the screen the relevant disclosure,  
15 and I've asked him what the patent says about Fig. 3. I  
16 believe that is squarely within what Your Honor said we  
17 could do.

18 MS. SWAROOP: Your Honor, if he deviates beyond  
19 the text of what his patent says about Fig. 3, that is a  
20 violation of Order 42.

21 JUDGE BHATTACHARYYA: Let's continue with the  
22 questioning. To the extent you believe there are portions  
23 of his testimony that are improper, we'll deal with it when  
24 we get to that point.

25 MS. SWAROOP: Thank you, Your Honor.



1 THE WITNESS: Can you repeat your question, then,  
2 please?

3 Q. Yes. The question was: What does your patent  
4 say about the example in Fig. 3?

5 A. Would you like a verbatim reading or paraphrased?

6 Q. Just a paraphrase for what the patent -- what the  
7 patent is showing in Fig. 3.

8 A. Yeah. So Fig. 3 is showing an arrangement of  
9 LEDs numbered 34 and a detector 36 which, again, can be a  
10 single element, multi-element, 1D array or 2D array, and all  
11 of that within a sensor head 32.

12 Q. And --

13 MS. SWAROOP: Object, move to strike everything  
14 describing the characters of the detector that's not stated  
15 here in this passage that counsel is showing Dr. Rowe.

16 MS. VREELAND: I think the response, Your Honor,  
17 would be that the patent in an earlier place says that that  
18 single detector can be multiple detectors.

19 MS. SWAROOP: Your Honor, now we have counsel  
20 arguing about the disclosure.

21 MS. VREELAND: Well, I think he --

22 MS. SWAROOP: Your Honor, he also used words like  
23 "it can be." It does appear that he is now interpreting the  
24 disclosure in direct violation of Order No. 42.

25 JUDGE BHATTACHARYYA: Can we take a break for a

1 minute?

2 MS. VREELAND: Absolutely.

3 MS. SWAROOP: Yes, Your Honor. It's page 3 of  
4 order 42.

5 (Brief recess.)

6 JUDGE BHATTACHARYYA: We're back on the record.

7 Dr. Rowe can testify regarding his personal  
8 knowledge about what the invention is. He can testify  
9 regarding his personal knowledge about what he wrote in the  
10 patent.

11 To the extent that that's what he is testifying  
12 about, it is going to be let in and given the appropriate  
13 weight, and counsel can argue about the appropriate weight  
14 it should be given in the post-hearing briefs, but he is not  
15 limited precisely to reading the patent.

16 MS. SWAROOP: Your Honor, can he be permitted to  
17 testify -- he is using words like "can" and "may be able to  
18 do this." That seems to be exceeding the disclosure of the  
19 patent in violation of Order 42 -- could be, it could be  
20 doing this.

21 JUDGE BHATTACHARYYA: I agree. I think he should  
22 avoid testimony like that. To the extent there can be some  
23 foundation laid for various options that he wrote about in  
24 the patent, that's permissible, but general discussion about  
25 what could theoretically happen is too much without a

1 foundation.

2 MS. SWAROOP: Thank you, Your Honor.

3 MS. VREELAND: Thank you.

4 Q. Why don't we just speed ahead and look at the  
5 embodiment that you illustrate in Fig. 8B and describe in  
6 the accompanying text at 1160 to 122.

7 What were you illustrating in Fig. 8B?

8 A. So in 8B we're showing the electro-optic sensor  
9 or one example of the electro-optic sensor on the back of a  
10 wristwatch.

11 Q. And in the accompanying text you say that any of  
12 the sensor geometries previously disclosed can be used for  
13 this application.

14 What sensor geometries had you previously  
15 disclosed in the patent?

16 A. The figures we were just -- we were just looking  
17 at, the Figs. 3 through 7, I believe they were.

18 Q. Okay. So it would have been included the  
19 illustrations that we previously discussed in Figs. 3  
20 through 7B?

21 A. Mm-hmm, correct.

22 Q. And was there any previously disclosed discussion  
23 of the sensor head?

24 A. Yes. Yes, quite a bit, yes.

25 Q. Okay. Great.

1 MS. VREELAND: Well, we'll stop there,  
2 Your Honor, since it's past Your Honor's stopping point. No  
3 further questions.

4 JUDGE BHATTACHARYYA: All right. Sounds good.  
5 There will be further questions tomorrow, I  
6 assume, Ms. Vreeland? Will you continue with the witness  
7 tomorrow?

8 MS. VREELAND: We'll pass the witness.

9 JUDGE BHATTACHARYYA: All right. So let's break  
10 for today.

11 Is there anything that counsel needed to bring up  
12 before we adjourn?

13 MS. SWAROOP: Yes, Your Honor.

14 JUDGE BHATTACHARYYA: Dr. Rowe, I'll see you  
15 tomorrow for Ms. Swaroop's questioning.

16 THE WITNESS: Okay. May I leave now, Your Honor?

17 JUDGE BHATTACHARYYA: Yes, you may leave. Thank  
18 you.

19 THE WITNESS: All right. Thank you.

20 MS. SWAROOP: Your Honor, on the issue of the  
21 clock, I did want to address one point.

22 I believe yesterday Mr. Mueller and this morning  
23 had indicated to you that Masimo was several hours -- had  
24 used several hours more of time than Masimo.

25 Based on our calculations, on the end of today,

1 C E R T I F I C A T E

2 TITLE: CERTAIN LIGHT-BASED PHYSIOLOGICAL MEASUREMENT DEVICES  
3 AND COMPONENTS THEREOF

4 INVESTIGATION NO.: 337-TA-1276

5 HEARING DATE: June 9, 2022

6 LOCATION: Washington, D.C. - Remote

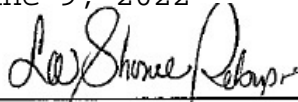
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above-referenced proceedings of the U.S. International Trade  
Commission.

10 Date: June 9, 2022

11 Signed:

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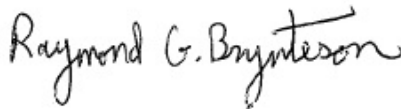


12 Signature of the Contractor or the Authorized Contractor's  
13 Representative

14 I hereby certify that I am not the court reporter  
and that I have proofread the above-referenced transcript of  
15 the proceedings of the U.S. International Trade Commission  
against the aforementioned court reporter's notes and  
16 recordings for accuracy in transcription in the spelling,  
hyphenation, punctuation and speaker identification and did  
17 not make any changes of a substantive nature. The  
foregoing/attached transcript is a true, correct and  
complete transcription of the proceedings.

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19 ss//



20 I hereby certify that I reported the  
21 above-referenced proceedings of the U.S. International Trade  
Commission and caused to be prepared from my record media  
22 and notes of the proceedings a true, correct and complete  
verbatim recording of the proceedings.

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25

# UNITED STATES INTERNATIONAL TRADE COMMISSION

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In the Matter of

Investigation No.

CERTAIN LIGHT-BASED PHYSIOLOGICAL 337-TA-1276

MEASUREMENT DEVICES AND COMPONENTS

THEREOF

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REVISED AND CORRECTED TRANSCRIPT

OPEN/CLOSED SESSIONS

Pages: 1168 through 1459

Place: Washington, D.C.

Date: June 10, 2022

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**Appx41264**

1 UNITED STATES INTERNATIONAL TRADE COMMISSION

2 Washington, D.C.

3 Before the Honorable Monica Bhattacharyya

4 Administrative Law Judge

5

6 -----x

7 In the Matter of Investigation No.

8

9 CERTAIN LIGHT-BASED PHYSIOLOGICAL 337-TA-1276

10 MEASUREMENT DEVICES AND COMPONENTS

11 THEREOF

12 -----x

13

14

15 EVIDENTIARY HEARING

16 Friday, June 10, 2022

17 Volume V

18

19

20 The parties met via remote videoconferencing  
21 pursuant to notice of the Administrative Law Judge at 9:30  
22 a.m. Eastern.

23

24

25 Reported by: Linda S. Kinkade RDR CRR RMR RPR CSR

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2 [All parties appeared via remote videoconferencing and/or  
3 telephonically.]

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17 \*\*\* Index appears at end of transcript \*\*\*

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1 THE WITNESS: Good morning, Your Honor. Good  
2 morning everyone.

3 JUDGE BHATTACHARYYA: Do you understand that  
4 you're under an obligation to tell the truth in your  
5 testimony today?

6 THE WITNESS: Yes.

7 STEVE WARREN,  
8 having been first duly sworn and/or affirmed  
9 on his oath, was thereafter examined and testified as  
10 follows:

11 JUDGE BHATTACHARYYA: Thank you. You may proceed  
12 counsel.

13 DIRECT EXAMINATION

14 BY MS. VREELAND:

15 Q. Dr. Warren, could you begin by introducing  
16 yourself to Her Honor?

17 A. Yes. My name is Steve Warren. I'm a professor  
18 at Kansas State University.

19 Q. You got your K-State purple on today?

20 A. I do, yes, I have to represent.

21 Q. How long have you been a professor at K-State?

22 A. I started in '99, so about 23 years.

23 Q. And can you briefly describe your educational  
24 background?

25 A. Yes. I have three degrees in electrical

1 engineering: a Bachelor's and a Master's degree from Kansas  
2 State, and then a doctorate from the University of Texas at  
3 Austin, and then I've also done a postdoctoral appointment  
4 at Sandia National Labs.

5 Q. What was the focus of your research, your Ph.D.  
6 research, at the University of Texas?

7 A. That research was biomedical research. It was  
8 light tissue interaction or laser tissue interaction, where  
9 we were using argon ion laser light to diagnose coronary  
10 artery and aorta disease progression.

11 Q. And what did you do after receiving your Ph.D.?

12 A. I finished my doctorate, and then I went to  
13 Sandia National Labs as a postdoctoral appointment, and I  
14 worked for a group there that was working on a personal  
15 status monitor project.

16 Q. Was that a light-based sensor?

17 A. It incorporated a light-based sensor, among other  
18 things, yes.

19 Q. What did you do after completing your work at  
20 Sandia?

21 A. After I finished at Sandia, I went to Kansas  
22 State University to begin a professor appointment and I've  
23 been there since.

24 Q. How did you choose to go back to K-State?

25 A. Well, I'm from Kansas originally, so it was nice

1 to bring kids back to grandparents.

2 Q. What are your current responsibilities at Kansas  
3 State?

4 A. It is a three-prong appointment. It's a  
5 research, teaching, and service appointment.

6 Q. Okay. What technologies have you focused on at  
7 Kansas State?

8 A. We've worked on a lot of things, but for research  
9 it's been primarily physiological monitoring tools, wearable  
10 sensors, pulse oximeters specifically, signal analysis, and  
11 engineering education, to name a few.

12 Q. Can you provide some -- have you built or  
13 developed any physiological sensors over the time that  
14 you've worked at K-State?

15 A. We've built dozens of different varieties of  
16 sensors, accelerometers, pulse oximeters, motion units,  
17 conductive plethysmographs, all kinds of different things.

18 Q. Can you provide a few examples?

19 A. Yeah. A lot of our work deals with what I would  
20 call vulnerable populations. So the elderly, for example,  
21 we've looked at various portable or ambulatory monitors for  
22 use with aging.

23 Some of those units, if you turn them a quarter  
24 turn, you get a different sensor every time you turn it a  
25 quarter turn. We've looked at portable pulse oximeters in

1           A.    Yeah.  A person of ordinary skill would have  
2   known at that time that you could include a plurality of  
3   photodiodes.  I have examples here that note four or more  
4   where they could be arranged radially, meaning in a circular  
5   arrangement, or in what we would say is a rectilinear grid  
6   or a Cartesian coordinate system.

7                    So some of the examples of note here are from  
8   1978.  I've noted two.  There's Orr, RX-495, and Cramer,  
9   RX-670, and then, again, we see McCarthy on the upper row,  
10   RX-489.  Mendelson in the top is really popular, RX-458.  
11   And then if you look at the bottom, the Konig reference,  
12   RX-487, has made an impact in this arena.

13          Q.    If we were to turn to the next slide, would you  
14   be able to name even more?  And I won't stop you.

15          A.    This slide has some really good ones.  A good  
16   example, I include, Lumidigm RX-411, in the upper left,  
17   which we'll talk about much more later.

18                   The Avni article in the upper right, second from  
19   the right, is an interesting one, because that's a  
20   swallowable GI pill that uses light as a sensing mechanism.  
21   I listed our own sensor in the upper right, K-State 6D,  
22   RPX-6.

23          Q.    I'm going to stop you there.  I think we got a  
24   full list.

25                   I'm going to ask you on the next slide, in July



1 of 2008, what was known about the use of openings with  
2 opaque surfaces over photodiodes?

3 A. Well, I would say in 2008 and many decades prior,  
4 openings are a way for light or to allow light to get to a  
5 detector. A detector can't detect light without some sort  
6 of opening above it.

7 Q. And if we were to turn to the next slide, can you  
8 provide some examples before 2008 -- July of 2008 -- of  
9 devices that combine these concepts that you've been talking  
10 about -- multiple LEDs, four or more photodiodes, and  
11 openings over those photodiodes?

12 A. Yes. None of these tools existed in isolation.  
13 A designer would have used a collection of a grouping or  
14 permutation of many of them in their work.

15 One I really like a lot is Smart, RX-473, because  
16 it incorporates the LEDs, the photodiodes, the opaque  
17 material, the interior surfaces, the opaque surfaces, and  
18 the openings all in one bundle, 50 years ago.

19 Q. What are the others that you've identified on  
20 this slide? And just by name and exhibit number.

21 A. Okay. Haar, RX-667, and then McCarthy, RX-489,  
22 Lumidigm, RX-411, and then finally Imai, RX-1220.

23 Q. If we can turn to the next slide.

24 In July of 2008, what was known about the use of  
25 transmissive coverings or windows over photodiodes?

1           A.    I noted earlier that you need an opening to allow  
2   light to reach a detector.  A window is another way to allow  
3   that to happen where a window is a physical piece of  
4   material, or we call it a transmissive covering, where the  
5   covering would allow light through, but it would also  
6   physically protect the detector from dust and debris and  
7   dirt, liquid, things of that nature.

8           Q.    What are your favorite examples here?

9           A.    I'll pick a few.  I really like Cramer RX-670 in  
10   the upper left, because it's more than 40 years old.  
11   Nippon, or what I call Jaib, RX-665, next to it.  Seiko,  
12   we'll hear about in a moment, RX-666, and then also Haar,  
13   RX-667.  And I might point out we also did this with Kansas  
14   State, RX-648.

15          Q.    If we could turn to the last slide in this  
16   series.

17                   In July of 2008, what was known about the use of  
18   structures protruding into the tissue in optical sensors?

19          A.    So a person of ordinary skill would have already  
20   known that you could take a structure, we'll call it a  
21   protrusion or a sensor head, and push that into tissue, and  
22   what that would enable is that would push residual blood out  
23   of the way and increase your AC-to-DC signal ratio, meaning  
24   that you would see the tissue perfusion in a better way.

25                   And there were a number of designs that did this.

1 Again, I like Smart, because it's so old, RX-473, but  
2 Cramer, next to it, RX-670, also implemented this mechanism.

3 And Seiko in the bottom left, Seiko 131, which is  
4 RX-666, not only implemented it, but explained well why the  
5 technique was important and why it worked.

6 Q. If we could go to the next slide.

7 Professor Warren, we're going to come back to the  
8 Apple Watch later, but until then just a few preliminary  
9 questions.

10 How long have optical sensors included four or  
11 more sets of LEDs?

12 A. At least since 1990, so 30 years.

13 Q. How long have optical sensors included four or  
14 more photodiodes arranged in quadrants?

15 A. Cramer 1978 would be a good example, so 40 years.

16 Q. How long have optical sensors included openings  
17 with opaque surfaces over photodiodes?

18 A. That goes all the way back to Herczfeld and Smart  
19 in the late '60s.

20 Q. And how long have optical sensors included convex  
21 protrusions to conform to a measurement site?

22 A. I would offer Smart for that one, early '70s.

23 Q. We're going to turn now to RDX-8.88.

24 You mentioned earlier that you have built pulse  
25 oximeters with your students in laboratory classes. Do you

1 worked at Sandia in Albuquerque in the mid-'90s.

2 Q. How did you first become aware of the Lumidigm  
3 '212 patent?

4 A. I found this patent when I was doing a recessed  
5 detector search online.

6 Q. Can we call it Lumidigm for short?

7 A. Yes, that's fine.

8 Q. How would you characterize Lumidigm's  
9 disclosures?

10 A. The spec -- I think the real novelty is in the  
11 idea of a personal identification system that uses liveness  
12 as an additional indicator.

13 But one of the other benefits of the  
14 specification is that it includes a collation of what was  
15 known about the time of optical sensor heads that were used  
16 in reflectance mode for spectroscopy purposes in terms of  
17 their various LED and photodiode detector layouts.

18 Q. We're going to pull on to the screen RX-411,  
19 Figures 3 through 7B.

20 What does Lumidigm describe in connection with  
21 these figures?

22 A. These figures are various examples or exemplary  
23 ideas of ways to lay out a variety of sources and detectors  
24 in reflectance mode on a sensor such as this, including in  
25 radial and rectilinear and Cartesian layout.

1 Q. Does Lumidigm say anything about when you might  
2 want to use various of these iterations of LEDs and  
3 photodiodes?

4 A. Well, Lumidigm states that any one of the given  
5 sources, for example, can be sets of LEDs, and any one of  
6 the given detectors can be a single detector or a plurality  
7 or an array of detectors.

8 And, generally, with regard to how they might be  
9 used, there's a section in the spec called extended  
10 functionality that speaks to many different application  
11 areas.

12 Q. We're going to put on the screen Figs. 8A, 8B,  
13 and 8C from the Lumidigm patent.

14 What was Lumidigm illustrating in these figures?

15 A. These three figures illustrate portable  
16 embodiments of this particular sensing approach. Key fob on  
17 the left, Figure 8A, Figure 8B would be a watch embodiment,  
18 and Figure 8C would be an embodiment on the surface of a  
19 phone.

20 Q. And what does Lumidigm say about the types of  
21 LEDs and photodiodes you can use in any of these  
22 embodiments?

23 A. Lumidigm states, with regard to any of these  
24 portable embodiments, that any of the sensor geometries that  
25 are presented in the specification can be applied.

1           And what I mean by that specifically is Figs. 1  
2   through 7, for example, all show different layouts of sensor  
3   heads, but additionally the specification itself describes  
4   different geometrical layouts, different signal management  
5   techniques, including what it calls a compound curvature  
6   that would essentially relate to the shape of the sensor  
7   head itself.

8           Q.   We're going to turn to the next slide, then.

9           Were you here for Ms. Swaroop's opening  
10   statement?

11          A.   I was, yes.

12          Q.   Did you hear her describe Lumidigm's functions as  
13   a wish list?

14          A.   Yes, I did.

15          Q.   Have you studied the functions referenced in the  
16   Lumidigm patent that these devices can perform?

17          A.   I have, yes.

18          Q.   And how would you characterize these functions?

19          A.   I would characterize these functions as known  
20   applications in reflectance spectroscopy where one might  
21   want to employ then a reflectance mode sensor.

22                A fruit ripeness example is a good one. While  
23   that sounds esoteric in this context, this has been used  
24   with Japanese fruit markets forever as a means to assess  
25   fruit quality.

1 Q. And Professor Warren, have you compared  
2 Lumidigm's disclosures to the asserted Poeze claims?

3 A. Yes.

4 Q. And what have you concluded?

5 A. My conclusion is that Lumidigm invalidates every  
6 one of those independent claim limitations for those  
7 asserted patents.

8 Q. And have you reached an alternative opinion on  
9 whether Lumidigm alone would, at a minimum, render them  
10 obvious?

11 A. Yes. My alternative opinion would be that these  
12 claim limitations would be obvious in view of Lumidigm.

13 Q. If we could turn to the next slide.

14 In reaching your opinions, what level of skill  
15 did you assume a person of skill in the art would have had  
16 in July of 2008?

17 A. I've accepted this definition, which is a person  
18 with a bachelor's degree in a discipline related to either  
19 electrical, computer, or software technologies, plus one to  
20 two years of work experience including with physiological  
21 monitoring tools, or, alternatively, a master's degree in  
22 less than a year of related experience.

23 Q. We're going to show on the next slide your claim  
24 chart for 501, claim 12, and we're going to turn to the  
25 preamble of that claim.

1 curvature or the convex surface, any of those light  
2 management features could be incorporated into an  
3 embodiment, for example, such as 8B, which would be, we'll  
4 call it, the watch embodiment.

5 Q. If we could turn to the next slide, then.

6 What was your conclusion about how Lumidigm  
7 compares to '501 claim, 12?

8 A. My opinion is that Lumidigm as a singular  
9 reference anticipates or discloses every one of the claim  
10 limitations present in '501, claim 12.

11 Q. We're going to turn, then, to the next claim,  
12 '502, claim 22.

13 And am I correct that you have already explained  
14 the basis for your opinion that Lumidigm meets '502 elements  
15 19C and 19E in connection with your opinions on the similar  
16 elements of '501, claim 12?

17 A. Yes.

18 Q. Let's turn, then, to the preamble of '502, claim  
19 22, or the preamble of independent claim 19.

20 How does Lumidigm teach this?

21 A. This preamble is similar to the prior preamble,  
22 but it also adds the well-known idea of oxygen saturation --  
23 excuse me -- oxygen saturation as a result.

24 Lumidigm, again, addresses this through the  
25 wristwatch embodiment, so we'll go back to Fig. 8B, where



1 the wristwatch performs the functionality of, not only the  
2 biometric sensor or reader, but also extended functionality  
3 as a portable device that's mentioned later in the  
4 specification where I will go to, not only columns 11 for  
5 the wristwatch description, but also column 19, where there  
6 are two descriptions to a hemoglobin monitor, or two  
7 references to a hemoglobin monitor, but also to a system  
8 that can measure oxygenation and/or hemoglobin levels in the  
9 blood, or otherwise stated, to quantify oxygenation levels.

10 Q. Professor Warren, would a person of skill in the  
11 art in July of 2008 have needed any further details than  
12 these to know how to implement pulse oximetry functionality  
13 in Lumidigm's watch embodiment in 8B?

14 A. No, because it was a standard reflectance mode  
15 sensor application. We had already seen a number of  
16 publications in that area, and we got it to work ourselves  
17 in the laboratory several years prior. So a person of  
18 ordinary skill would not have needed any additional  
19 information to make that work in this kind of an embodiment.

20 Q. When you said we did it ourselves in the  
21 laboratory, were you referring to the measurements taken at  
22 the wrist?

23 A. Yes. I did it myself in the mid-'90s, and then  
24 when I started at Kansas State my own students built these  
25 sensors and worked with them on their wrists.

1 Q. You were here for the testimony of the Apple  
2 witnesses; is that correct?

3 A. Yes.

4 Q. So you're aware that it took Apple many years to  
5 implement blood oxygen measurements in the Apple Watch?

6 A. Yes, I am.

7 Q. And why did it take Apple so long, in your  
8 opinion and from the evidence you've seen, why did it take  
9 Apple so long to implement blood oxygen measurements in the  
10 Apple Watch?

11 A. Apple had a set of significant challenges to  
12 overcome. Not only were they severely limited on real  
13 estate, but they were also limited on processor capabilities  
14 given the amount of other applications that need to run also  
15 on the watch.

16 And even though these -- the simple light  
17 management problems such as addressed in the Poeze patents  
18 had already been essentially solved in many cases, there  
19 were still nuances of those light management features in  
20 addition to the algorithms that needed to be developed to  
21 make that entire package come together.

22 Q. Great. Let's turn to the next element, then,  
23 22A -- 19A.

24 MR. CLAASSEN: Your Honor, I want to object to  
25 that last question. That opinion testimony was not

1 disclosed in Dr. Warren's report.

2 MS. VREELAND: Your Honor, we can put on the  
3 screen the exact paragraph that discloses that. It's  
4 paragraph 244 of his opening report.

5 JUDGE BHATTACHARYYA: Please go ahead.

6 MS. VREELAND: I'm actually going to display 243  
7 and 244 for the context, and it's paragraphs 243 and 244.

8 Just for context, Your Honor, the discussion of  
9 the claim 22 Preamble refers to the earlier reference to  
10 measuring blood oxygen, one of the '501 dependent claims  
11 that is no longer in the case, but I'll show you the text  
12 there that's incorporated by reference.

13 So in paragraph 243 Dr. Warren provided the  
14 opinion that he just gave about how a person of skill in the  
15 art would understand how to implement Lumidigm's device in a  
16 pulse oximeter, and in paragraph 244 he explained how the  
17 Apple Watch -- the reasons why the Apple Watch took longer  
18 to develop and the challenges of the Apple Watch.

19 MR. CLAASSEN: Your Honor, slide -- the processor  
20 that was mentioned in slide 29 that Dr. Warren was  
21 discussing is not mentioned in this paragraph 244.

22 JUDGE BHATTACHARYYA: Could I see the remainder  
23 of 244, I just want to read the whole paragraph 244, and  
24 then slide 29.

25 MS. VREELAND: It was the preamble for claim 22.

1           Your Honor, for context, he was explaining why it  
2   took Apple longer to implement the blood oxygen measurement  
3   in the Apple Watch.

4           MR. CLAASSEN: Your Honor, if we could go back to  
5   the report.

6           JUDGE BHATTACHARYYA: Okay. Could you clarify,  
7   Mr. Claassen --

8           It's Mr. Claassen, correct?

9           MR. CLAASSEN: That's correct, Your Honor. Thank  
10   you.

11          JUDGE BHATTACHARYYA: Could you clarify exactly  
12   what you're objecting to in terms of his testimony?

13          MR. CLAASSEN: Your Honor, my understanding of  
14   what's stated in paragraph 244 is that Dr. Warren is  
15   discussing -- I'm trying to read it on the screen,  
16   Your Honor -- the attractiveness and accuracy and nothing  
17   about a processor or any specific use. He was just  
18   describing with respect to the slide that was presented.

19          MS. VREELAND: May I respond, Your Honor? He  
20   says in the paragraph that begins, "I understand," I  
21   understand it took years of work by the Apple engineers to  
22   develop a successful wrist-worn pulse oximeter for consumers  
23   that is also aesthetically pleasing and able to function in  
24   combination with the many other features of the Apple Watch.

25          I think that's what Professor Warren was just

1 explaining, that you had to put all that software together  
2 in a small watch.

3 MR. CLAASSEN: Your Honor, if the testimony is  
4 limited to what he states exactly in his report, we withdraw  
5 the objection, but we would like the testimony to be exactly  
6 what's in his report.

7 MS. VREELAND: Your Honor, I would certainly be  
8 happy to do that.

9 JUDGE BHATTACHARYYA: Okay. Why don't the  
10 parties -- if the parties can work it out, that's wonderful.  
11 We can revisit this later.

12 Q. We'll go on to the next element, then.

13 Can you explain how Lumidigm teaches -- if we  
14 could go to 19A and 22 --

15 A. Yes, this is a pair of claim limitations that are  
16 very similar in nature. They both speak to a plurality of  
17 emitters -- in the second case at least four emitters.

18 In the first case the plurality would comprise at  
19 least two light-emitting diodes, and in the second case each  
20 of the plurality of emitters would be a respective set of at  
21 least three LEDs.

22 So a plurality of sets of two or four emitters  
23 each of which had at least a set of three. This is a  
24 well-known idea in the literature, as I noted earlier, but  
25 with respect specifically to Lumidigm, Lumidigm includes

1 Figures 3 and -- let's see, 5, 7A and 7B -- where Lumidigm  
2 states that each of the locations for the LEDs, which,  
3 again, are the red dots on these figures, each of those  
4 locations can be comprised of LEDs with the same or  
5 different wavelengths, but also the light sources themselves  
6 can include sets of LEDs --

7 Q. Why don't we go --

8 A. -- at each location.

9 Q. Let's go, then, to the next limitation.

10 How does Lumidigm teach element 19B?

11 A. So this is the well-known idea of four  
12 photodiodes arranged on the user-worn device. Lumidigm  
13 addresses this specifically in Fig. 7A and 7B, where 7A  
14 incorporates five photodiodes in a linear arrangement, and  
15 Fig. 7B incorporates an 8x8 grid of 64 photodiodes.

16 Q. Let's turn, then, to element 19C or 19D, excuse  
17 me.

18 How does Lumidigm teach this?

19 A. The notion of an optically transparent material  
20 is, again, quite well-known where the material is in each of  
21 the openings. Lumidigm states in column 8 that an optical  
22 relay, which is not shown in the diagram, between the sensor  
23 and sensor surface and the skin, and helped to transfer  
24 light by directionally either from the light source from the  
25 skin or from the skin back to the detector.

1           And I've illustrated, for example, a well-known  
2   optical relay, which is a lens, in the opening of the  
3   photodiode that's depicted in Fig. 2, but Lumidigm also  
4   states that you can use fiber-optic faceplates for this  
5   purpose, where you could use a single faceplate for multiple  
6   openings or you could do an individual -- a person of skill  
7   would know that you could do an individual faceplate for  
8   each of the individual openings as a means to provide light  
9   but still optimize the process.

10          Q.   And what about the example, the fiber bundle,  
11   what would a person of skill in the art understand about  
12   that?

13          A.   Right. This is one that I mentioned in my report  
14   where you could use a fiber bundle to essentially direct the  
15   light from a portion of tissue straight to the detector as a  
16   means to optimize the detection process.

17          Q.   And in July 2008, what materials would a person  
18   of skill in the art recognize a fiber-optic faceplate or a  
19   fiber bundle would be made of?

20          A.   The individual fibers would have a glass core and  
21   then either a glass or a plastic cladding and then a  
22   protective layer. A fiber-optic faceplate, by the way, is  
23   like a bundle of spaghetti that you hold in your hand and  
24   you cut sideways so that you get all the little fibers lined  
25   up with one another.

1 Q. Why don't we go to the next element then, 19E,  
2 excuse me, dependent claims 20 and 21.

3 How does Lumidigm teach these?

4 A. These claims are paired -- they essentially  
5 relate to the well-known notion that, if your processor can  
6 receive a temperature signal, in this case from a  
7 thermistor, it can then adjust the operation of the  
8 user-worn device.

9 The importance of this, by the way, is that LEDs  
10 change their behavior depending on temperature. They, for  
11 example, will change their center wavelength if the  
12 temperature increases or decreases.

13 So these two claims speak to that, as does  
14 Lumidigm. And we can look at Lumidigm, for example, in  
15 column 14, where Lumidigm states the goal to perform  
16 explicit corrections to account for sensor to sensor  
17 variations or environmental influences of temperature that  
18 would involve the processor depicted in Fig. 9, and a person  
19 of ordinary skill would realize that such a temperature  
20 measurement could easily be done with a thermistor.

21 Q. If we could turn to the next element. Let me  
22 actually ask you about your conclusion.

23 What did you conclude, then, about how Lumidigm  
24 compares to '502, claim 22?

25 A. My opinion is that, as a single reference,



1 Lumidigm anticipates or discloses every one of these  
2 individual claim limitations.

3 Q. Let's turn then to '502, claim 28.

4 And am I correct that you have already explained  
5 the basis for your opinion that Lumidigm meets the preamble  
6 and elements 28D, E, F, G, and in connection with your  
7 opinions on the similar elements of the earlier claims?

8 A. Yes.

9 Q. Let's turn to element 28A, then.

10 How does Lumidigm teach elements 28A and 28B?

11 A. So these claims are similar to the earlier ones  
12 that -- but in this case we have a first set of LEDs and a  
13 second set of LEDs where, within the first set, there is the  
14 emission of light at a first wavelength and a second  
15 wavelength, and in the second set of LEDs there is the same,  
16 meaning an emission of light at the first wavelength and at  
17 the second wavelength.

18 And I'll go back in this case to this well-known  
19 idea as illustrated in Lumidigm Figs. 3 and 5 and 6 and 7A  
20 and 7B, which --

21 Q. Let's turn -- I'm sorry -- turn to the next slide  
22 before your further explanation.

23 How does Lumidigm teach the first wavelength and  
24 the second wavelength?

25 A. Right. I've illustrated here, and in this case

1 boss regions, all of which help to prevent light piping  
2 because of the fact that they are indeed opaque material.

3 Q. And what about Cramer's can?

4 A. Yeah, the can itself adds another layer of what  
5 we could say is opaque material. A person of ordinary skill  
6 would realize that the can would be made from aluminum or  
7 stainless steel or some material that was impervious to  
8 light as a means to prevent light piping.

9 Q. If we could turn to the next slide.

10 What, then, is the basis for your opinion that a  
11 person of skill in the art would have been motivated to  
12 combine Lumidigm's watch with Seiko's and Cramer's teachings  
13 of openings over photodiodes with opaque surfaces to avoid  
14 reduce or prevent light piping?

15 A. Well, again, it's a twofold response. The first  
16 note is that Lumidigm expressly states the need for openings  
17 over detectors that are themselves recessed in opaque  
18 material, but, regardless of that disclosure, which was  
19 well-known at the time, a person of ordinary skill could go  
20 to Seiko and Cramer and a number of other references that  
21 teach this particular concept.

22 Q. Let's turn to the next slide, then, and the  
23 limitations in '502 -- in the '502 and '648 claims relating  
24 to optically transparent materials or windows within or  
25 across the openings.

1           If we could turn to the next slide.

2           How do Seiko and Cramer teach these limitations?

3           A.   In Seiko, for example, these limitations are  
4   taught through the light transmittance plate that I already  
5   mentioned. It's a transparent material that allows light to  
6   reach the photodiode detector.

7           In Cramer, windows or transparent materials are  
8   taught two different ways. The first one, for example, is  
9   the lens that exists at the top of the can above the  
10   photodiode in this depiction, and the other is the windows  
11   that are between the raised boss regions as depicted in  
12   Fig. 6.

13          Q.   If we could turn to the next slide.

14           What is the basis for your opinion that a person  
15   of skill in the art would have been motivated to combine  
16   Lumidigm's watch with Seiko's and Cramer's teachings on the  
17   use of optically transparent materials and windows over or  
18   within openings -- over or within the openings over  
19   photodiodes?

20          A.   The basis for my opinion is, first, that Lumidigm  
21   expressly teaches this idea through the notion of an optical  
22   relay, which is a general way to say a transparent material  
23   for allowing light to pass.

24           And, in addition, independent of that idea, a  
25   person of ordinary skill would have known that windows could

1 be used and that Seiko 131 and Cramer would be suitable  
2 references to consult.

3 Q. Finally, then, let's turn to the limitation in  
4 the next slide -- limitation in claim 30 relating to a  
5 protrusion with chamfered edges.

6 How do Seiko and Cramer disclose this limitation?

7 A. Seiko discloses chamfered edges in several  
8 figures. I've noted Fig. 5 and Fig. 28 here where chamfered  
9 edges are illustrated in Fig. 5 at the edges of the  
10 protrusion, and in Fig. 28 on the opposite side of the  
11 sensor as a comfort mechanism.

12 And in Cramer, chamfered edges are incorporated  
13 in Fig. 3, as an example, where a chamfer allows the edge to  
14 transition from the main watch body to the raised boss area  
15 without a sharp, 90-degree orthogonal edge that would be  
16 uncomfortable for the user.

17 Q. And if we were to turn to the next slide, what is  
18 the basis for your opinion that a person of skill in the art  
19 would have been motivated to combine Lumidigm's watch with  
20 Seiko's and Cramer's teachings of protrusions with chamfered  
21 edges?

22 A. The basis for my opinion, again, is twofold. The  
23 first thought is that the compound curvature and the need  
24 for ergonomic features is expressly stated in Lumidigm.  
25 Additionally, a person of ordinary skill would understand

1 that chamfered edges have been around for many decades as a  
2 means to soften transitions between surfaces and make items  
3 such as watches more wearable.

4 Q. If we could turn to the next slide, I'd like to  
5 ask you about this combination of features that we've just  
6 discussed -- the convex surface, the openings, the windows,  
7 and the chamfered edges.

8 What is the basis for your opinion that a person  
9 of skill in the art would have been motivated to combine all  
10 these features in Lumidigm's watch?

11 A. Well, these features are well-known management  
12 features, and as a watch embodiment, for example, a person  
13 of ordinary skill would realize that there had been many  
14 other watch embodiments introduced into the literature,  
15 including Seiko and Cramer, and that they would then form a  
16 natural combination for teaching purposes.

17 Q. Now you mentioned that Seiko and Cramer focused  
18 on measuring pulse rate rather than blood oxygen. Does that  
19 impact your opinion in any way?

20 A. No, not at all, because the same light management  
21 features that you need to incorporate for a single  
22 excitation wavelength to allow a pulse rate determination  
23 are the same light management features that you need to  
24 incorporate with multiple wavelengths to employ pulse  
25 oximetry or any other kind of spectroscopy measurement.

1 section on the removal of residual blood out of the way as a  
2 result of added pressure so that the pulsatile signal would  
3 be more available to the field of view of the sensor.

4 Q. Okay.

5 A. Cramer, likewise --

6 Q. Go ahead.

7 A. Well, Cramer, likewise, taught the idea where the  
8 Cramer specification states that pressure needs to be  
9 applied in order to push the boss region into tissue to make  
10 an effective measurement, and that the boss arrangement with  
11 its convex curvatures is effective to minimize the  
12 discomfort to the wearer.

13 Q. And have you, finally, have you seen any evidence  
14 either over the course of this case or at this trial that  
15 Apple copied the alleged inventions in the Poeze patents?

16 A. I have not.

17 Q. Let's turn, then, briefly to the written  
18 descriptions in the Poeze patents. We're going to put on  
19 the screen RDX-8131.

20 Have you also considered whether the Poeze  
21 specification supports and enables the asserted Poeze  
22 claims?

23 A. Yes, I have considered that.

24 Q. And just briefly, have you identified any  
25 embodiments in the Poeze patents that include the claimed

1 limitations of features recited in '501, claim 12, '502  
2 claim 22, '502 claim 28, and '648, claim 12?

3 A. No. As an example, the combination of three  
4 LEDs, three photodiodes, and a plurality of openings over  
5 the photodiodes with opaque lateral surfaces as in claim 12,  
6 I can't find a single embodiment. The same is true of these  
7 other descriptions that are on the same viewgraph.

8 Q. Okay. We're going to go to RDX-8.133.

9 Have you identified any -- any discussion or any  
10 embodiments in the Poeze specification that include four  
11 emitters each with three LEDs?

12 A. No.

13 Q. If we could turn to the next slide.

14 Have you identified any discussion in the Poeze  
15 specification of the use of multiple sets of LEDs each with  
16 LEDs emitting at a first wavelength and a second wavelength?

17 A. I have not found one, no.

18 Q. If we could turn to the next slide.

19 Have you identified anything in the Poeze  
20 specification that would tell a person of skill in the art  
21 how to implement a user interface with a touchscreen?

22 A. I have only found two brief references to  
23 touchscreens, so no.

24 Q. Finally, on the next slide, have you seen  
25 anything in the Poeze specification that provides guidance

1 on reducing or avoiding light piping other than a general  
2 reference to the use of opaque materials?

3 A. No. I've just seen a vague correlation between  
4 the two, that's it.

5 Q. Let's turn, then, to the issue of the basis for  
6 your opinion that the Apple products do not infringe.

7 And you were here for the testimony of Apple's  
8 engineers, correct?

9 A. That's correct.

10 Q. And have you also compared Apple's accused  
11 products to the asserted Poeze claims?

12 A. Yes.

13 Q. And what did you conclude?

14 A. I have concluded that they do not infringe those  
15 claims.

16 MS. VREELAND: Your Honor, we would like to go on  
17 the Apple confidential record with Apple CBI.

18 (Whereupon, the hearing proceeded in confidential  
19 session.)

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**APPX41350-41356**  
**ENTIRELY REDACTED**

1 JUDGE BHATTACHARYYA: Hello again, Dr. Madisetti.

2 THE WITNESS: Good afternoon, Your Honor.

3 JUDGE BHATTACHARYYA: Just to be on the safe side

4 I will ask you to swear or affirm again.

5 VIJAY MADISETTI,

6 having been first duly sworn and/or affirmed  
7 on his oath, was thereafter examined and testified further  
8 as follows:

9 DIRECT EXAMINATION

10 BY MR. CLAUSSEN:

11 Q. Good afternoon, Dr. Madisetti.

12 A. Good afternoon, sir.

13 Q. Did you prepare demonstrative slides regarding  
14 your validity analysis for this case?

15 A. Yes.

16 Q. Let's take a look at CDX-12C, please. We can  
17 turn to slide 2.

18 Dr. Madisetti, can you please explain the summary  
19 of your opinions regarding validity?

20 A. Yes. I'm offering an opinion with respect to the  
21 asserted claims of the '501, the '502, the '648, and the  
22 '745. It is my opinion that Apple has failed to show that  
23 any asserted claim is anticipated or rendered obvious. They  
24 originally had nine grounds challenging '501, '502, and '648  
25 patents and three grounds challenging '745 patent. My

1 opinions apply to all these grounds.

2 The specification in my opinion adequately  
3 supports the asserted claims under Section 112, and  
4 objective evidence confirms nonobviousness of the asserted  
5 claims under the asserted grounds.

6 Q. Let's turn to the next slide, slide 3.

7 What materials did you analyze in forming your  
8 opinions on validity?

9 A. I reviewed the patents, the file histories. I  
10 also reviewed the product references. I applied the  
11 knowledge of a POSITA. I looked at the expert reports. I  
12 responded to them. I reviewed the deposition testimonies,  
13 where relevant, the documentary evidence that I had at my  
14 possession and the physicals and did some testing again.

15 Q. You mentioned something called a POSITA. What is  
16 the level of skill in the art that you applied?

17 A. Yes. As I describe in the next slide, for these  
18 '501, '502, and '648, and '745 patents in the relevant time  
19 frame, that's 2008 and 2015, it was a person with working  
20 knowledge of physiological monitoring technologies, having a  
21 BS degree in the academic disciplines that I list here,  
22 electrical, computer, or software; some amount of training;  
23 and one to two years of related work experience in these  
24 areas. Alternatively, a person could have a higher degree,  
25 such as an MS degree, with less than a year of work

1 experience. I also -- my opinions also apply under Apple's  
2 experts level of skill in the art.

3 Q. Turning to slide 7, what is shown on this slide?

4 A. Yes. These are the nine grounds that Apple had  
5 originally applied. For the Multi-Detector Patents, which  
6 are the '501, '502, and the '648, and now I think based on  
7 today's presentation by Dr. Warren, only six of these  
8 grounds remain, 1 through 6, which are based on Lumidigm.

9 As you can see, as I tried to show from this  
10 particular chart, that out of the nine grounds almost all  
11 the references that I've highlighted in yellow have been  
12 presented to the USPTO. And the only references that appear  
13 to remain are Lumidigm and Apple 047 and a Bluetooth board.

14 Q. Turning to slide 9, please explain your analysis  
15 regarding Lumidigm.

16 A. Yes. With respect to Lumidigm, Lumidigm has  
17 several problems, and I list them here, and then I will  
18 explain a little more.

19 Lumidigm does not disclose or suggest at least  
20 the following claim features and elements:

21 There is no protrusion comprising a convex  
22 surface. This directly applies to claim elements '501, 1C,  
23 claim 12, '502, 19C, and 28E, '648, 8D and 20C.

24 It has no protrusion at all or over an interior  
25 surface. This applies to '501, 1C, '502, 28E. It has no

1 photodiodes disclosed '501, 1B, '502, 19B, 28C, 6488C, and  
2 20B. It has no openings or through holes in protrusion or  
3 windows in opening. And this applies to claim elements 1D  
4 of the '501, 19C and 19D of the '502, 28F and 28G of the  
5 '502, and 8E, 20D, and 20E of the '648.

6 It has no disclosure of SpO2 calculations or  
7 measurements. This affects the '502, 19 preamble, 28  
8 preamble, and the '648, claim 12. It has no claimed  
9 cavities, '502, 28H; no opaque lateral surface or opaque  
10 material configured to avoid or reduce light piping, element  
11 1E of the '501, element 28F of the '502, element 24 -- claim  
12 24 of the '648.

13 It has no thermistor, no adjustment responsive to  
14 temperature, claim 20 of the '502, claim 21 of the '502,  
15 claimed 28D and 28I of the '502.

16 And the only passing references to hemoglobin or  
17 oxygen levels as something called extended functionality.  
18 And I refer here, for example, to Fig. 2 that the Apple  
19 seems to include as a part of their analysis.

20 Q. Turning to the next slide, please explain your  
21 analysis regarding the extended functionality of Lumidigm.

22 A. Yes. As I said, Apple relies on a passing  
23 mention of hemoglobin in Lumidigm. Lumidigm is just a  
24 biometric identifier device. Looking at RX-411 in columns  
25 3, 35-37, 4, 7-29, 10, 11-21, and 19, 16-28, none of these

1 very vague mentions of hemoglobin link it to Fig. 8  
2 embodiment that's shown on the right.

3           There's no mention of oxygenation and/or  
4 hemoglobin levels, other than a broad discussion of what I  
5 call as aspirational extended functionality. So, again,  
6 there's no link to Fig. 8B. There's no disclosure or  
7 suggestion of Lumidigm being configured to noninvasively --  
8 noninvasively measure oxygen or oxygen saturation.

9           So those are some of the comments I make with  
10 respect to how Lumidigm does not disclose this  
11 functionality.

12           Q. Turning to the next slide, please explain your  
13 analysis regarding the lack of a protrusion comprising a  
14 convex surface in Lumidigm.

15           A. Yes. Lumidigm sensors have a flat sensor  
16 surface, 39, as shown here on Fig. 2.

17           And Lumidigm says the sensor head 32 may have  
18 some compound curvature of the optical surface, which is  
19 Lumidigm at column 7, 58-63.

20           But if you look at that disclosure on the bottom  
21 right, that is described that the sensor head may have --  
22 also have a compound curvature on the optical surface to  
23 match the profile of a device on which it's mounted.

24           So if it were a wristwatch and it were mounted on  
25 the hand, it would have a concave curvature at best. So

1 this is what Dr. Rowe, who is an inventor, confirms that I  
2 describe on bullet 3, that Rowe admits that a concave  
3 compound curvature would better approximate users tissue,  
4 his deposition testimony CX-279C at 68-69.

5 So even this passing mention, if applied to  
6 Fig. 8B would run contrary to Apple's incorrect argument  
7 that somehow compound curvature could be convex, which I  
8 disagree with.

9 Second is that Apple's argument is, again, trying  
10 to conflate this 39 with some sort of protrusion. It is  
11 unclear whether it is conflating this optical surface as  
12 having some sort of protrusion. There's no distinction  
13 between a protrusion or an interior surface. There's no  
14 disclosure of any sort of cavities or any opaque wall that's  
15 formed.

16 All that is disclosed is some sort of movement of  
17 this surface 39 up or down. That does not make a  
18 protrusion. That does not make an interior surface that's  
19 distinct from a protrusion. It does not satisfy all these  
20 other features. Therefore, Lumidigm fails to disclose or  
21 suggest to a POSITA a protrusion comprising a convex surface  
22 arranged over or above the interior surface or photodiodes.

23 And Dr. Warren admitted that this figure is a  
24 flat sensor surface.

25 Q. Dr. Madisetti, you heard Dr. Warren testify about

1 something called Kansas State 6D, right?

2 A. Yes.

3 Q. Turning to slide 15, can you please briefly  
4 explain Kansas State 6D?

5 A. Yes. Kansas State 6D was mentioned in passing.  
6 It is an undergraduate project from more than 20 years ago.  
7 It's a very -- it's not a user-worn device. It has many  
8 problems. It has a foam type of description that is shown  
9 here in the middle. And there's no evidence that it was  
10 ever -- it ever resulted as a user-worn device. So it looks  
11 like a very simple, basic undergraduate class project.

12 Q. Dr. Madisetti, is your understanding that Kansas  
13 State 6D is from approximately 2004 or 2005?

14 A. Yes, it's more than 17 years, that's my  
15 understanding.

16 Q. Turning to slide 23, please explain your analysis  
17 of Apple's third reference, Cramer?

18 A. Yes.

19 Q. Excuse me. Seiko 131.

20 A. Yes. Seiko 131 is a second reference suggested  
21 by Apple. And there's, again, no protrusion comprising a  
22 convex surface with openings. And this applies to elements  
23 1D of the '501, 19C, 28F of the '502, 8E and 20D of '648.

24 It just talks about one photo transistor, 32, and  
25 so there's no protrusion. There is no opaque lateral



1 surface/material configured to avoid or reduce light piping.  
2 This directly applies to 1E of the '501, 28F of the '502,  
3 claim 24 of the '648.

4 The alleged protrusion, 341, is just transparent  
5 glass. And Exhibit 666, column 10 and lines 30-33 and  
6 36-41, there are no windows in the openings or openings in  
7 the protrusion. There's no protrusion comprising one or  
8 more chamfered edges. This applies to claim 30 of the '648.  
9 And the no windows applies to '502, 19D, 28G of the '502,  
10 and 8F and 20D of the '648.

11 So I defer to the embodiment that's related with  
12 respect to Fig. 28, that I cross out that and say that  
13 that's not a protrusion comprising a convex surface with  
14 openings.

15 Q. Turning to slide 25, please explain your analysis  
16 of Apple's third reference, Cramer.

17 A. Cramer, again, does not disclose or suggest at  
18 least the following claim features and elements:

19 So, first of all, there are three embodiments I  
20 show on the right, Figs. 2, Fig. 3, and Fig. 5. Fig. 5 is  
21 just a pressure sensor. It's not even an optical sensor.  
22 So it's not relevant in my opinion to this matter.

23 Further, with respect to Figs. 2 and Fig. 3, the  
24 side view of Fig. 3 and then the top view as shown in  
25 Fig. 2. As you can see, Your Honor, there are just two

1 rings. These are called bosses. This is not even a  
2 protrusion, as claimed.

3           There's no covering over -- there's no protrusion  
4 arranged over or above the interior surface or the  
5 photodiodes. The photodiodes are shown in red -- sorry --  
6 the emitter is shown in red. And in blue you have the  
7 detectors.

8           And as you can see, the protrusion, alleged  
9 protrusion, is not a protrusion, it's not over these  
10 photodiodes, there is -- as claimed.

11           So, secondly, this protrusion, this alleged  
12 protrusion, in other words, there's no protrusion comprising  
13 a convex surface as well. And Fig. 5 embodiment is just a  
14 pressure transducer. And it's not having any photodiodes.

15           The Figs. 2 and 3, the bosses 22 and 22A, are  
16 just annular rings. They are not the claimed protrusion  
17 with its properties. This directly applies to claim  
18 elements 1C of the '501, 19C of the '502, 28D of the '502,  
19 28C of the '648, and then also claim elements 1C of the  
20 '501, claim 12 of the '501, 19C, 28D of the '502, 8D and 20C  
21 of the '648.

22           There are no openings or windows in the openings  
23 in the protrusion as claimed. Again, elements 1D of the  
24 '501, 19C, 19D, and 29F and 28G of the '502, and 8E, 8F, and  
25 20D of the '648.

1           And there's no protrusion comprising the opaque  
2 surface materials or the chamfered edges. And this affects  
3 1E of the '501, 28F of the '502, claim 24 and 30 of the  
4 '648.

5           Q. Turning to slide 27, please explain your analysis  
6 of Webster.

7           A. Yes. Webster was, again, cited in the grounds.  
8 And first, again, they refer to the exhibit, for example,  
9 RX-35. What it is referring to, Your Honor, is that it is a  
10 transcutaneous P02 sensor. Transcutaneous is not  
11 noninvasive. It is invasive.

12           So there's no thermistor in a user-worn Sp02  
13 sensor. Webster describes a transcutaneous Po2 sensor or  
14 electrode using a heating element.

15           There's no motivation in Webster to add  
16 thermistor to adjust operation of Lumidigm's Fig. 8B  
17 biometric system. So this affects claim 20, 21 of the '502,  
18 28D and 28I of the '502.

19           Further, there are no windows and  
20 openings/through holes of the protrusion as claimed. This  
21 affects 19D, 28G of the '502, 8F and 20D of the '648.

22           And there's no motivation in Webster to add  
23 windows to Lumidigm's biometric system. There's no  
24 explanation of how the specific features of the reference is  
25 to be combined and no expectation of success.

1 I will discuss these a little more after I  
2 discuss a couple more of these prior art references.

3 Q. Turning to slide 29, please explain your analysis  
4 of Apple 047.

5 A. Apple 047 is the reference, I believe, that is in  
6 part of Apple's combinations. Again, this is RX-673 shown  
7 on the right. It refers to an iPad-type device, and you can  
8 see compared to the size of the hand. It's not user-worn  
9 physiological measurement device with a touchscreen  
10 configured to display oxygen saturation measurements,  
11 affecting claim element 28K of the '502.

12 A person of ordinary skill would not look to the  
13 iPad-like device of Apple 047 to improve upon Fig. 8B of the  
14 biometric system.

15 And then there's no motivation to combine  
16 Lumidigm's biometric system with a touchscreen of '047 to  
17 display a measurement that Lumidigm does not take. We heard  
18 from Dr. Rowe that the SpO2 measurement yesterday was not --  
19 was not present.

20 There's no motivation to combine -- or this is  
21 not in the grounds anymore, so we can omit the last bullet.

22 Q. Now that we have discussed the shortcomings of  
23 the references in Apple's combinations regarding Lumidigm,  
24 can we turn to the next slide. Can you explain your  
25 analysis -- excuse me, slide 14 -- slide 13 --

1 A. Yes. So we have the grounds with --

2 Q. Let's turn to slide 13, Dr. Madisetti.

3 A. Yes, slide 13. So here after I have -- we have  
4 to go to 13?

5 Q. Correct.

6 A. So here after I explain the basic references and  
7 what they are missing, I also explain why there's no  
8 motivation or reasonable expectation of success for, for  
9 example, the protrusion comprising a convex surface.

10 Adding a protrusion comprising a convex surface  
11 would add excessive pressure to the measurement site and  
12 displace blood away from the sensor, which was known to  
13 cause measurement errors.

14 So Mendelson '799, which is Exhibit CX-1733, on  
15 pages 2 to 47, which is a reference, a prior art reference,  
16 explicitly describes that variations in contact pressure  
17 between the sensor and the skin can cause large errors in  
18 reflection pulse oximetry (as compared to transmission pulse  
19 oximetry), so reflection pulse oximetry is what is done in  
20 the wrist, since some of the blood near the superficial  
21 layers of the skin may be normally displaced away from the  
22 sensor housing towards deeper subcutaneous structures.

23 Consequently, the highly reflective bloodless  
24 tissue compartment near the surface of the skin would cause  
25 large errors and so on.

1           So this clearly discourages one of ordinary skill  
2     in the art and provides no motivation or an expectation of  
3     success that the combination would actually work or have a  
4     reasonable expectation of success.

5           Further, Rowe confirms that concave, not convex,  
6     in the context of Lumidigm, would better approximate tissue  
7     shape and provide better coupling with respect to Lumidigm.

8           So, therefore, one of ordinary skill in the art  
9     would not understand the motivation or expect success and,  
10    thus, would understand that adding a protrusion comprising a  
11    convex surface would undesirably also add to the form  
12    factor, in addition to causing measurement errors.

13          Q.    Dr. Madisetti, you mentioned Mendelson '799.  
14    That's CX-1733, right?

15          A.    Yes.

16          Q.    Turning to slide 30 --

17          A.    Sorry. Slide 14.

18          Q.    Let's go to slide 14.

19          A.    Yes. Further, continuing on, the motivation to  
20    combine and no expectation of success, there's no suggestion  
21    or motivation to combine Lumidigm's Fig. 8B biometric system  
22    with the alleged protrusions of Seiko 131 or Cramer, for the  
23    reasons that are explained in Lumidigm alone.

24                In addition, the features of Seiko 131 and Cramer  
25    that Apple relies on as a protrusion would be less

1 comfortable and does not align with Lumidigm's goal of  
2 incorporating ergonomic features. I rely, again, on RX-411,  
3 column 7, 57-63.

4 Further, there's no motivation to combine  
5 Lumidigm with an opaque lateral surface or an opaque  
6 material configured to avoid, prevent, or reduce light  
7 piping.

8 Lumidigm, Seiko 131, and Cramer fail to recognize  
9 light piping as a problem at all or motivate a solution to  
10 address it. Any discussion in Lumidigm is not a discussion  
11 of the light piping problem because it includes the surface  
12 of the skin in Lumidigm.

13 There's no explanation of how these specific  
14 features of these references would be combined. And, thus,  
15 there's no expectation of success as to the combination of  
16 Lumidigm and Seiko 131 or Cramer.

17 Q. Now that we've discussed the shortcomings of  
18 Apple's combinations, can you explain your analysis on slide  
19 30, please?

20 A. Yes. So going to the Lumidigm by itself, ground  
21 1, whether it's anticipation or obviousness under Lumidigm,  
22 Lumidigm has several problems.

23 It is -- for example, it doesn't have a user-worn  
24 device configured to noninvasively measure oxygen saturation  
25 as confirmed by Lumidigm and Dr. Rowe. And here is the

1 applicable claim elements that I read earlier.

2 On the right I say this is not present in  
3 Lumidigm, and there is no motivation to combine and no  
4 expectation of success. And, further, it looks like a  
5 hindsight that has driven this sort of combination, where  
6 pieces of limitations were added piece by piece using the  
7 asserted claims as a roadmap.

8 Then with respect to the user-worn device  
9 configured to noninvasively measure a physiological  
10 parameter and determine measurements of a user's tissue,  
11 again, with respect to the '501 and the '648, the preambles  
12 1 and 20, these are not present. And there's no motivation  
13 to combine or an expectation of success, and they are driven  
14 by hindsight.

15 Similarly, with respect to the emitters and sets  
16 of LEDs, each of two or more LEDs, they are not present in  
17 Lumidigm. And there's no motivation or expectation of  
18 success to modify it. And this affects limitations that  
19 I've described here, 19A, 20, 28A, 28B, 8A, and 8B of the  
20 '502 and the '648.

21 And then these additional limitations of at least  
22 three photodiodes arranged on an interior surface of the  
23 user-worn device, those limitations, again, are not present  
24 and there is no motivation or expectation of success, other  
25 than hindsight.



1           There is no protrusion comprising a convex  
2 surface for the reasons that I've described. This is not  
3 there. In fact, it teaches away from using a convex  
4 surface.

5           And this is, again, a hindsight in my opinion.  
6 And there's no expectation of success or a motivation to  
7 combine with respect to the limitations that I described  
8 earlier.

9           Finally, these openings or through holes through  
10 the protrusion, and over or aligned with photodiodes is not  
11 present. There's no motivation to modify or combine or  
12 expectation of success. This is, again, hindsight. It  
13 affects the limitations 1D, 19C, 28F, 8E, and 20D of the  
14 Asserted Patents.

15           And, finally, there's no disclosure or  
16 obviousness of opaque lateral surface configured to avoid  
17 light piping through the protrusion, opaque surface  
18 configured to reduce light piping, or other such limitations  
19 of 1E, 28F, and 24 of the '501, '502, and the '648. Again,  
20 because these are not present, and this is hindsight, and no  
21 motivation to modify or expect success, given the teachings  
22 of Lumidigm.

23           Q.   Turning to slide 31, Dr. Madisetti, please very  
24 briefly explain your analysis on this slide.

25           A.   Yes. With respect to, I think it continues there

1 with this additional limitations that are missing. The  
2 window or optically transparent material in protrusion  
3 openings or through holes is not present. There is no  
4 motivation to modify. Again, hindsight.

5 Again, it does not calculate SpO2. Again, this  
6 is not present. That's why I say no. And there's no  
7 motivation to modify or expectation of success. Again,  
8 hindsight. There's no one or more processors configured to  
9 calculate a physiological measurement, network interface,  
10 touchscreen memory are not mentioned. Again, the same  
11 reasons, MC/ES hindsight.

12 The thermistor, adjust operation responsive to  
13 temperature signal is not present, again, no motivation or  
14 hindsight -- based on hindsight, and a protrusion further  
15 comprising one or more chamfered edges is not present. And  
16 there's no motivation to add it or expectation of success as  
17 driven by hindsight.

18 Q. Turning to the next slide, slide 32,  
19 Dr. Madisetti please very briefly explain your analysis on  
20 this slide.

21 A. Yes. As I described in my analysis for Lumidigm  
22 and I described Seiko and Cramer, the limitations that are,  
23 again, not present and not -- and there's no motivation to  
24 modify or expectation of success and driven by hindsight  
25 that it's not a user device, it's not a user-worn device

1 that is configured to noninvasively measure oxygen  
2 saturation, it's not a user device configured to  
3 noninvasively measure a physiological parameter, there are  
4 no emitter sets, each with two or more LEDs, at least three  
5 photodiodes arranged is, again, not present, protrusion  
6 comprising a convex surface is not present, openings or  
7 through holes through the protrusion over or aligned with  
8 the photodiodes are not present, and the protrusion, as I  
9 said, there's no motivation or expectation of success to  
10 combine it with Seiko 131, for the reasons that I mentioned,  
11 and there's no opaque electrical surface that affects all  
12 these.

13 Q. Turning to the next slide, your analysis  
14 continues.

15 A. Yes. With respect to continuing with ground 2,  
16 the window or optically transparent material in protrusion  
17 openings or through holes again is not present in any of the  
18 three in the combination. And there is no motivation or  
19 expectation to modify.

20 It is driven, again, by hindsight. And all these  
21 other such limitations, such as one or more processors,  
22 network interface, on which Apple depends on Lumidigm,  
23 again, are not present. And there's no thermistor, and  
24 there's no motivation to modify. It's, again, driven by  
25 hindsight, no expectation of success.

1           Finally, the chamfered edge is not present in any  
2 of the references, nor there is a motivation to modify or  
3 expectation of success, it is purely hindsight.

4           Q.   Turning to slide 34, please very briefly explain  
5 your analysis of this slide.

6           A.   Yes. This ground 3 adds Lumidigm with Webster.  
7 And as I described earlier, Lumidigm has lots of problems  
8 with respect to these limitations shown here. And Webster  
9 only is focused on the thermistor, and thermistor was in the  
10 case of an invasive sensor, that was subcutaneous or  
11 transcutaneous.

12           For that reason, for the reasons that I describe  
13 here, none of the limitations of '502 patent, claim 22,  
14 which depends on claim 19 are either -- are rendered obvious  
15 by ground 3.

16           Q.   Turning to slide 35, please very briefly explain  
17 your analysis here.

18           A.   Yes. With respect to ground 4, the Lumidigm and  
19 Seiko 131, Cramer, and Webster, again, fail because for the  
20 '502 patent, claim 22, as I describe here, for each of the  
21 limitations in claim 19, they are not present in any of the  
22 references. There's no motivation to combine, expectation  
23 of success. In fact, Lumidigm teaches away against  
24 protrusions.

25           And, further, there's no optically transparent

1 material disclosed within any of the openings. And if you  
2 continue on the next slide.

3 Q. Slide 36, please.

4 A. Yes; so, again, the limitations 19E, 20, 21 and  
5 22 are not met, because they are not present and there is no  
6 motivation to modify, expectation of success, it is all  
7 hindsight-driven.

8 Q. Turning to slide 37, please very briefly explain  
9 your analysis on this slide.

10 A. Yes. Ground 5, the Apple 047, which is the  
11 iPad-like interface, again, this, as I described, that is  
12 all the features of the '502, claim 28 and are not present  
13 for the reasons I described earlier. There's no motivation  
14 to combine with Apple, no expectation of success. It is all  
15 hindsight-driven.

16 And if you go to the next slide, where they try  
17 to combine the Apple 047, it is for the network interface,  
18 touchscreen and memory. And as I describe here, there's no  
19 motivation or expectation of success, it is  
20 hindsight-driven. And all the limitations I list are not  
21 present in any of these references, nor rendered obvious.

22 Q. Turning to slide 39, please very briefly explain  
23 your analysis on this slide.

24 A. Yes. Slide 39, I rely on my previous analysis  
25 for Lumidigm, Seiko 131, Cramer, Webster, and Apple 047,

1 again, for the reasons that I described earlier, claim 28  
2 and its limitations are, again, not present, and there's no  
3 motivation to modify or expectation of success. And in my  
4 opinion they are driven by hindsight for the reasons that I  
5 mentioned in the earlier grounds.

6 Q. Turning to slide 40, please very briefly explain  
7 your analysis on this slide.

8 A. Continuing on ground 6, as I show here, with the,  
9 no, no, no, all these are not present in any of these  
10 references, Lumidigm, Seiko 131, Cramer, or Webster. And  
11 there's no motivation to combine or expectation of success.  
12 For these reasons, it's my opinion that ground 6 does not  
13 render obvious the asserted claims.

14 Q. I want to move on now to your analysis of written  
15 description support for the Multi-Detector Patents. Do you  
16 understand that I'd like to move to that topic?

17 A. Yes.

18 Q. Let's turn to slide 44, please. Please explain  
19 your analysis regarding written description support.

20 A. Yes. There is full written description support  
21 for multiple LEDs, three or more photodiodes, and opaque  
22 lateral surfaces.

23 So, as I described, with respect to Fig. 7B in  
24 Exhibit JX-1, there is full support based on Figures 1,  
25 Figures 3 to 4, Figures 7A, 7B, columns -- for the

1 limitations based on columns 26, column 27, column 38,  
2 column 43, column 44, column 7, and column 6. Multiple LEDs  
3 with at least three photodiodes is disclosed because the  
4 sensor 301 includes all the features of the earlier sensors  
5 100 and 200, column 18, lines 39 to 42.

6 So then the specification clearly discloses the  
7 sensors can be 701, can be implemented with any of the  
8 sensors 101, 201, and 301 described above, column 26, 25  
9 through 29.

10 Fig. 7B and Fig. 49 confirm that sensor 701 has  
11 multiple emitters in housing 704 and multiple detectors.  
12 And Fig. 14I discloses emitters 1404 are depicted in the  
13 emitter shell, numerous embodiments with multiple emitters  
14 and detectors, Figs. 1, 7, and 13.

15 The specification also describes in column 7,  
16 column 27, column 28 that any protrusion embodiment may  
17 include hard or opaque plastic with openings as claimed.  
18 The shielding enclosure or box made of copper, opaque  
19 material that includes openings as claimed.

20 So in my opinion specification adequately claims  
21 configurations with multiple LEDs, three or more  
22 photodiodes, and openings with opaque lateral surfaces  
23 within the same embodiment.

24 Q. And, Dr. Madisetti, you said adequately claims;  
25 is that correct?

1 A. Adequately describes and discloses.

2 Q. So what is your opinion regarding written  
3 description on this issue?

4 A. It is my opinion that the claims with multiple  
5 LEDs, three or more photodiodes and opaque lateral surfaces  
6 have full written description support.

7 Q. Turning to slide 45, please explain your analysis  
8 regarding written descriptions support for sets of LEDs in  
9 at least four emitters.

10 A. Yes, as I describe again with respect to the  
11 embodiment of Fig. 7B, emitters 104 included in the sensors  
12 from 101, 201, 301, and 701 and described throughout the  
13 specification as described as including sets of LEDs with  
14 different wavelengths.

15 I refer, again, to columns 12, lines 3-25, column  
16 18, 39-42, and column 26, 25-29, which show that sets of  
17 optical sources that are capable of emitting visible and  
18 near infrared optical radiation, and then Fig. 13 talks  
19 about multistream -- discloses multistream process 1300  
20 applicable to any of the sensors described above and using  
21 emitter sets.

22 So sensors are described as having -- as many  
23 sets of LEDs, as a number of -- as the number of detectors  
24 or even more sets of LEDs than the number of detectors,  
25 Figs. 13, 33, column 33, 18-51.



1           The specification, JX-1, column 12, 16-25,  
2 provides additional disclosure of claimed sets and emitters  
3 as I cite here.

4           Q.   Turning to the next slide, please explain your  
5 analysis of written description and enablement for an opaque  
6 material configured to substantially reduce light piping?

7           A.   In my opinion written description and enablement  
8 are disclosed by the specification itself and supported by  
9 the specification itself of the '501, '502, and the '648,  
10 where it explicitly describes protrusion can advantageously  
11 include hard opaque plastic, helpful in reducing light  
12 noise, including by light piping, Exhibit JX-1, column 7,  
13 65-8, column 8, line 7.

14           The JX-1 at column 25, 48-59, describes adding --  
15 discloses adding height of the protrusion reduces light  
16 piping. And I refer to the portion of the specification  
17 here that adding height provides for greater thinning of the  
18 measurement site and added height assists in deflecting  
19 light piped through the sensor.

20           So I, again, refer to column 7, column 25, column  
21 37, column 43, and Figs. 3C and 7B in the lines that I cite.

22           Q.   Dr. Madisetti, turning back to slide 45, please  
23 explain your opinion regarding written description support  
24 for the claimed LEDs and emitters.

25           A.   Counsel, which slide are you referring to?

1 Q. Slide 45, please.

2 A. Okay. So with respect to the sets of LEDs and at  
3 least four emitters, I think I covered this.

4 Q. Can you please briefly explain the basis for your  
5 opinion?

6 A. As I said here, the emitters 104 included in  
7 sensors 101, 201, 301, and 701, I refer to the  
8 specification, column 12, 3-25, column 18, 39-42, column 26,  
9 25-29, Figs. 7, 11, and 13 that describe emitters comprising  
10 sets of LEDs.

11 I refer to Figure 13, which refers to  
12 multi-process 1300 -- multistream process 1300 applicable to  
13 any of the sensors described above and using emitter sets,  
14 Figs. 13, column 33, lines 18-51.

15 And also the specification in column 12, 16  
16 through 25, provides additional further disclosure of the  
17 claimed sets and emitters, where it discloses that emitter  
18 104 can be arranged in an array, such as described in U.S.  
19 Publication Number 2006/0211924, filed September 21, 2006,  
20 titled Multiple Wavelength Sensor Emitters, the disclosure  
21 of which is incorporated by reference in its entirety.  
22 Other --

23 Q. Dr. Madisetti, my question may not have been  
24 clear enough. What was your overall final opinion based  
25 upon this analysis?

1           A.    Oh, I see. I'm sorry for that. It's my opinion  
2   that there is full written description support and  
3   enablement support for all the claims and their limitations,  
4   including those that I described.

5           Q.    And turning back to slide 47 where we were, what  
6   was your opinion regarding enablement of the touchscreen  
7   display and indicia of measurements?

8           A.    Yes, as I show in the embodiment of Fig. 2C,  
9   there is a disclosure of a touchscreen display that's in the  
10   context of the pulse oximeter measurement. And I rely upon  
11   specification columns 16, lines 39-42, that talks about --  
12   that discloses the features of monitoring devices 200 shown  
13   in Figures 2A through 2D that may be combined with features  
14   of other monitoring devices 200 shown.

15               And the specification further explains the  
16   monitoring device 200 can employ any of a variety of user  
17   interface designs, such as touchscreens.

18               And the monitor 209 can include display 210B that  
19   can indicate a measurement. Other analytes and other forms  
20   of display can also appear on the monitor 209B. And I refer  
21   to 209C shown in Fig. 2C, also includes straps 214C that  
22   allow the monitor 209C to be attached to the patient's limb  
23   or the like. I refer to Figures 2A through 2D, columns 16,  
24   17, 18, and 17.

25           Q.    Going back to slide 46, Dr. Madisetti, could you

1 it was known to use a temperature sensor on the LED  
2 substrate to compensate for wavelength changes due to  
3 temperature, correct?

4 A. I would say so, yes.

5 MR. SELWYN: Thank you. Nothing further.

6 MR. LATEEF: We have nothing further, Your Honor.  
7 Thank you.

8 JUDGE BHATTACHARYYA: Thank you, Mr. Goldberg.  
9 You may step down.

10 MR. RE: Good afternoon, Your Honor.

11 JUDGE BHATTACHARYYA: Good afternoon.

12 MR. RE: Masimo and Cercacor call as their next  
13 witness Mr. Robert Stoll.

14 JUDGE BHATTACHARYYA: Let's make sure Apple's  
15 counsel is here.

16 MS. FRAZIER: Your Honor, Ms. Vreeland will do  
17 the cross-examination for this.

18 JUDGE BHATTACHARYYA: Good afternoon, Mr. Stoll.

19 THE WITNESS: Good afternoon, Your Honor.

20 JUDGE BHATTACHARYYA: Do you understand that  
21 you're under an obligation to tell the truth here today?

22 THE WITNESS: I do.

23 ROBERT STOLL,

24 having been first duly sworn and/or affirmed  
25 on his oath, was thereafter examined and testified as

1 follows:

2 JUDGE BHATTACHARYYA: Thank you.

3 THE WITNESS: Thank you.

4 DIRECT EXAMINATION

5 BY MR. RE:

6 Q. Mr. Stoll, where do you work today?

7 A. I work for Faegre Drinker Biddle & Reath in  
8 Washington, D.C.

9 Q. And can you briefly summarize your experience in  
10 the area of Patent Office requirements and procedures?

11 A. I spent 29 years at the Patent and Trademark  
12 Office. I started off as a junior examiner. I was promoted  
13 to a supervisory examiner. I had several promotions in the  
14 management and policy area. And I finished my career at the  
15 Patent and Trademark Office as the Commissioner for Patents  
16 where I oversaw eight thousand patent examiners and all  
17 policy and procedures related to patent prosecution. And I  
18 ended there in the end of 2011, at which time I began at  
19 Faegre, and I've been there about ten years, where I  
20 supervise patent prosecution, I testify, I've represented  
21 people through the Office of Enrollment and Discipline, I do  
22 policy issues, and I troubleshoot complex applications.

23 MR. RE: Your Honor, because I know this is  
24 undisputed, Masimo and Cercacor offer Mr. Stoll as an expert  
25 on Patent Office practice and procedure.

1 MS. VREELAND: No objection, Your Honor.

2 JUDGE BHATTACHARYYA: At this time -- let me  
3 formally -- at this time Mr. Stoll is admitted as an expert  
4 on Patent Office practice and procedure.

5 MR. RE: Thank you, Your Honor.

6 Q. Mr. Stoll, are you familiar with Apple's  
7 allegations that the '501, '502, '648, and '745 patents are  
8 unenforceable due to prosecution laches?

9 A. I am.

10 Q. And did you analyze specifically those  
11 allegations?

12 A. I did.

13 Q. And what did you do to analyze the sufficiency or  
14 the correctness of those allegations?

15 A. I looked at the entire prosecution history of the  
16 parent, the parents of those applications.

17 Q. And I understand you prepared a demonstrative  
18 slide to help illustrate your testimony.

19 Can we call that up?

20 What does this slide generally show?

21 A. It shows key dates in the parent applications of  
22 the '501, the '502, and the '648.

23 Q. And do you understand that Apple alleges that  
24 there was a five-year gap from the filing of the '352  
25 application in 2010 to the filing of the '290 application in

1 2015?

2 A. I do, but I don't really understand what the gap  
3 is or what any gap is. This shows quite clearly that  
4 prosecution was progressing in these three applications in a  
5 normal pace consistent with practice at the Patent and  
6 Trademark Office in continuing applications, and I don't see  
7 any delay.

8 Q. Okay. I wonder if you can also explain using  
9 this chart that I understand there was an abandonment of the  
10 first case. Do you see that?

11 A. I do.

12 Q. Did that abandonment in any way cause any delay  
13 whatsoever in the prosecution of these patent applications?

14 A. It did not.

15 Q. And how do you know that?

16 A. Because I can see that the 829,352 was filed way  
17 before the application of the 534,827 and was progressing in  
18 a normal pace for a continuing application.

19 Q. I also notice that there's a publication date of  
20 February 4th, 2010. How does that affect your opinions with  
21 regard to prosecution laches?

22 A. Well --

23 MS. VREELAND: Your Honor, we would object to the  
24 extent there would be any opinions on the ultimate issue. I  
25 think Your Honor allowed him for purposes of Patent Office

1 practice and procedure.

2 JUDGE BHATTACHARYYA: That's correct.

3 Mr. Re, I'm assuming you're not seeking to elicit  
4 opinions on the ultimate issue of prosecution laches.

5 MR. RE: No. I'll withdraw and rephrase.

6 BY MR. RE:

7 Q. What's the practical effect of publication of the  
8 application back in 2010?

9 A. Well, you can see that on February 4th, 2010,  
10 application number 827 published, which means that the  
11 specification is in the public domain, and anyone can look  
12 at the specification and the prosecution of the applications  
13 after that, and they can know that, in fact, the subject  
14 matter contained in that specification could be claimed at a  
15 later date in either that particular application or  
16 continuing applications as specified by statute.

17 Q. I understand you've prepared another slide with  
18 regard to the '745 prosecution; is that right?

19 A. I did.

20 Q. Can we call that up?

21 What does this slide show?

22 A. This slide shows the key dates in the prosecution  
23 of the parent of the '745 application.

24 Q. Can you explain your opinion that this shows that  
25 the '745 patent application followed normal and acceptable



1 continuation practice?

2 A. Absolutely. You can see that it's published in  
3 January of 2017. You can see that there are actions going  
4 back and forth between the Examiner and the applicant. You  
5 can see that it was issued.

6 Well, there's a Notice of Allowance on July 29th,  
7 2019, and then there was a Petition to Withdraw to Consider  
8 References, and a fairly quick Notice of Allowance after  
9 that and payment of the issue fee.

10 Q. Based on your experience, are you familiar with  
11 the ways in which a patentee might delay prosecution?

12 A. Yes, I am.

13 Q. And explain what those ways are.

14 A. Well, you could refuse to take an allowance, you  
15 could delay an allowance, you could abandon allowed  
16 application, you could not progress the prosecution of an  
17 application in a manner that conforms with normal practice,  
18 and you can take more time than you should with respect to  
19 responding to actions.

20 Q. And based on your review, did you form an opinion  
21 as to whether any of those types of activities took place  
22 during the prosecution of the Masimo patents at issue here?

23 A. I did, and there was no delay, and there was none  
24 of those actions that occurred, and this -- the prosecution  
25 followed normal prosecution as provided by the statutes.

1 Q. Now I notice in the first parent it seems like  
2 there was some delay with regard to issuance of the first  
3 Office Action. Did you notice that?

4 A. Yes. I think there was one -- there was a delay  
5 in another one as well, and it was not uncommon back in that  
6 time period to have two and a half to three years before the  
7 Patent and Trademark Office picked up an application.

8 Q. So that's a delay caused by the Patent Office  
9 waiting to pick up the application, right?

10 A. Yes, it is.

11 MS. VREELAND: Object to the leading.

12 Q. Why does it take the Patent Office sometimes so  
13 long --

14 JUDGE BHATTACHARYYA: Mr. Re, can you respond to  
15 the objection?

16 MR. RE: I'll withdraw. I'll rephrase.

17 JUDGE BHATTACHARYYA: All right. Then the answer  
18 is stricken to that question.

19 Q. Why does it take the Patent Office so long to  
20 pick up an application to issue a First Office Action  
21 allowance or First Office Action response?

22 A. Back in this time frame, we were in excess of  
23 525,000 patent applications filed per year, they're in a  
24 queue, and they normally examine the first received, and it  
25 takes a while for the Court to get to the applications that

1 are later filed.

2 Q. So based on your review of the file histories of  
3 the patents at issue in this investigation, of which you are  
4 opining, what is your final conclusion with regard to the  
5 prosecution of the Poeze and '745 patent families?

6 A. There was a continuous unbroken chain of patent  
7 prosecution. There was no delay. And these conform with  
8 the practices of continuation as provided for by practice.  
9 I saw no issues related to any delay in the prosecution of  
10 these applications.

11 MR. RE: I have no further questions. I pass the  
12 witness.

13 MS. VREELAND: Your Honor, we would like to take  
14 up the implications of this testimony in our post-hearing  
15 briefing, but we have no questions at this time.

16 JUDGE BHATTACHARYYA: Thank you.

17 MR. RE: Thank you.

18 JUDGE BHATTACHARYYA: Thank you, Mr. Stoll.

19 THE WITNESS: Thank you. Have a great day,  
20 Your Honor.

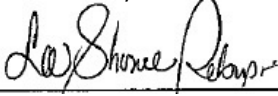
21 MS. SWAROOP: Your Honor, our next witness will  
22 be Daniel McGavock, and Mr. Laquer will be conducting that  
23 examination.

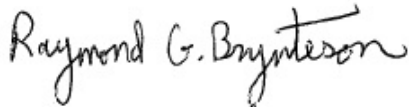
24 MR. LAQUER: Good afternoon.


25 THE WITNESS: Good afternoon.

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2	RX-0271C
3	RX-0272C
4	RX-0273C
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6	RX-0275C
7	RX-0276C
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9	RX-0353
10	RX-0366
11	RX-0368
12	RX-0381
13	RX-0397
14	RX-0414C
15	RX-0458
16	ADMITTED PURSUANT TO ORDER NO. 56
17	RX-1397C
18	RX-1447C
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1 C E R T I F I C A T E  
2 TITLE: CERTAIN LIGHT-BASED PHYSIOLOGICAL MEASUREMENT DEVICES  
3 AND COMPONENTS THEREOF  
4 INVESTIGATION NO.: 337-TA-1276  
5 HEARING DATE: June 10, 2022  
6 LOCATION: Washington, D.C. - Remote  
7 NATURE OF HEARING: Evidentiary Hearing

8 I hereby certify that the foregoing/attached  
9 transcript is a true, correct and complete record of the  
10 above-referenced proceedings of the U.S. International Trade  
11 Commission.  
12 Date: June 29, 2022  
13 Signed:   
14 ss//  
15 Signature of the Contractor or the Authorized Contractor's  
16 Representative

17 I hereby certify that I am not the court reporter  
18 and that I have proofread the above-referenced transcript of  
19 the proceedings of the U.S. International Trade Commission  
20 against the aforementioned court reporter's notes and  
21 recordings for accuracy in transcription in the spelling,  
22 hyphenation, punctuation and speaker identification and did  
23 not make any changes of a substantive nature. The  
24 foregoing/attached transcript is a true, correct and  
25 complete transcription of the proceedings.  
Signed:  
ss// 

26 I hereby certify that I reported the  
27 above-referenced proceedings of the U.S. International Trade  
28 Commission and caused to be prepared from my record media  
29 and notes of the proceedings a true, correct and complete  
30 verbatim recording of the proceedings.  
Signed:  
ss// 



Document title: How to use the Blood Oxygen app on Apple Watch Series 6 or Series 7 - Apple Support

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User: Matthew.Friedrichs

**Mannheimer**  
**Exhibit 10**  
**(2-10-22)**

WWW.DIGITALEVIDENCEGROUP.COM

PDF REFERENCE #: 3rQbxJoTXnHiW3eoDSiXBF



Store

Mac

iPad

iPhone

Watch

TV

Music

Support



CX-0010

## How to use the Blood Oxygen app on Apple Watch Series 6 or Series 7

The Blood Oxygen app can allow you to measure the oxygen level of your blood on-demand directly from your wrist, providing you with insights into your overall wellness.



Measurements taken with the Blood Oxygen app are not intended for medical use and are only designed for general fitness and wellness purposes.

The Blood Oxygen app is only available in certain countries and regions. [Learn where the Blood Oxygen app is available.](#)

### What is blood oxygen

Your blood oxygen level represents the percentage of oxygen your red blood cells carry from your lungs to the rest of your body. Knowing how well your blood performs this vital task can help you understand your overall wellness.

The majority of people have a blood oxygen level of 95 - 100%. However, some people live a normal life with blood oxygen levels below 95%. Slightly lower values while sleeping are expected, and some users might experience values below 95%.

### How to use the Blood Oxygen app

Make sure that you meet the below requirements and follow the steps to set up the Blood Oxygen app.

#### Here's what you need

- Make sure that the Blood Oxygen app is available in your country or region. You will be able to see this during the setup process.
- Update your iPhone 6s or later to the [latest version of iOS](#).
- Update your Apple Watch Series 6 or Series 7 to the [latest version of watchOS](#).\*
- The Blood Oxygen app is not available for use by people under 18 years old. You can confirm or [set up your age in your Health Profile](#).

\*The Blood Oxygen app is not available if you [set up your Apple Watch with Family Setup](#).

#### Set up the Blood Oxygen app and background readings

1. On your iPhone, open the Health app.
2. Follow the onscreen steps. If you don't see a prompt to set up, tap the Browse tab, then tap Respiratory > Blood Oxygen > Enable.
3. After you complete setup, open the Blood Oxygen app on your Apple Watch to measure your blood oxygen levels.

If you still don't see the Blood Oxygen app on your Apple Watch, you can search the App Store on your Apple Watch.

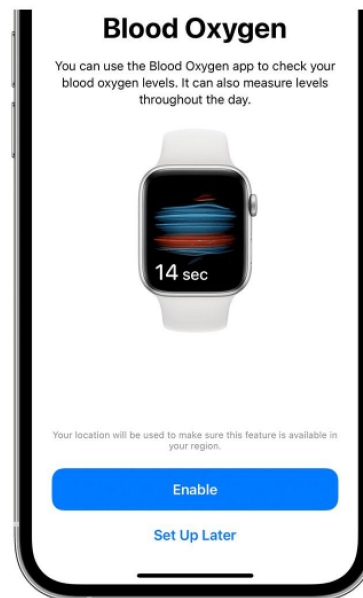


2. Follow the onscreen steps. If you don't see a prompt to set up, tap the Browse tab, then tap Respiratory > Blood Oxygen > Enable.

3. After you complete setup, open the Blood Oxygen app on your Apple Watch to measure your blood oxygen levels.

If you still don't see the Blood Oxygen app on your Apple Watch, you can search the App Store on your Apple Watch for Blood Oxygen and download it.

The Blood Oxygen app is installed during the setup in the Health app. [If you deleted the Blood Oxygen app, you can install it again](#) from the App Store on your Apple Watch if you've completed the Blood Oxygen app setup.



### How to take a blood oxygen measurement

You can take a blood oxygen measurement at any time with the Blood Oxygen app.

1. Make sure that your Apple Watch is snug but comfortable on your wrist.
2. Open the Blood Oxygen app on your Apple Watch.
3. Stay still, and make sure your wrist is flat with the Apple Watch facing up.
4. Tap Start, then keep your arm steady for 15 seconds.
5. Wait. The measurement takes 15 seconds. At the end of the measurement, [you will receive the results](#).
6. Tap Done.

### How to get the best results

1. Rest your arms on a table or in your lap while you take a measurement. Keep your wrist and palm down and flat, and hold as still as you can.
2. Make sure that your Apple Watch isn't loose on your wrist. The [band should be snug but comfortable](#), and the back of your Apple Watch needs to be touching your wrist.
3. Make sure that the back of your Apple Watch is flush with the top of your wrist. If your wrist bones interfere with this, move your watch 1 to 2 inches up your arm away from your wrist bone.



### Additional factors



3. Make sure that the back of your Apple Watch is flush with the top of your wrist. If your wrist bones interfere with this, move your watch 1 to 2 inches up your arm away from your wrist bone.



CX-0010

### Additional factors

Even under ideal conditions, your Apple Watch may not be able to get a reliable blood oxygen measurement every time. For a small percentage of users, various factors may make it impossible to get any blood oxygen measurement.

- Skin perfusion (or how much blood flows through your skin) can impact measurements. Skin perfusion varies significantly from person to person and can also be impacted by the environment. If you are out in the cold, for example, the skin perfusion in your wrist might be too low for the sensor to work with the Blood Oxygen app to get a measurement.
- Permanent or temporary changes to your skin, such as some tattoos, can also impact performance. The ink, pattern, and saturation of some tattoos can block light from the sensor, making it difficult for the Blood Oxygen app to get a measurement.
- Motion is another factor that can affect your ability to get successful background or on-demand measurements. Certain postures, such as arms hanging by your side or fingers in a fist position will also result in unsuccessful measurements.
- If your heart rate is too high (above 150 bpm) while at rest, you won't be able to get a successful blood oxygen measurement.

### About background measurements



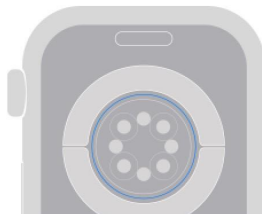
The Blood Oxygen app on your Apple Watch will occasionally measure your blood oxygen levels if background measurements are on. This will usually happen when you are not moving. Depending on how active you are, the number of readings collected each day and the time between these readings will vary. Blood oxygen measurements use a bright red light that shines against your wrist, so it may be more visible in dark environments. If you find the light distracting, you can turn off background measurements.

1. Open the Settings app on your Apple Watch.
2. Tap Blood Oxygen, then turn off In Sleep Focus and In Theater Mode.

Blood oxygen measurements only occur during sleep if the [Track Sleep with Apple Watch](#) setting is turned on.

### How the Blood Oxygen app works

In Apple Watch Series 6 and Series 7, the optical heart sensor has been redesigned to add blood oxygen measurement capabilities. During a blood oxygen measurement, the back crystal shines red and green LEDs and infrared light onto your wrist. Photodiodes then measure the amount of light reflected back.





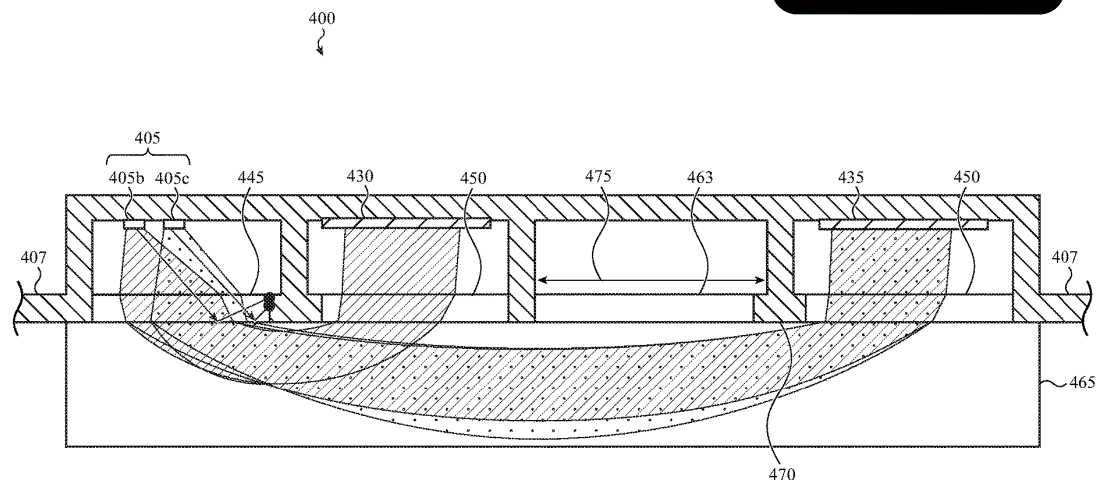
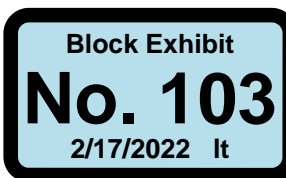
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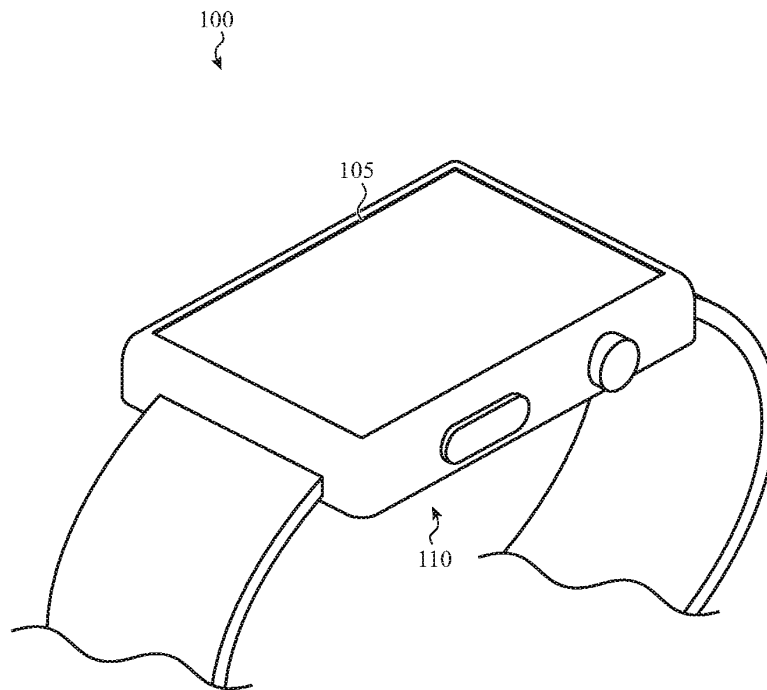
(19) **United States**(12) **Patent Application Publication**  
**Venugopal et al.**(10) **Pub. No.: US 2021/0093237 A1**(43) **Pub. Date: Apr. 1, 2021**(54) **PHYSIOLOGICAL MONITORING SYSTEM  
FOR MEASURING OXYGEN SATURATION***H01L 31/173* (2006.01)*A61L 31/02* (2006.01)*A61B 5/00* (2006.01)(71) Applicant: **Apple Inc.**, Cupertino, CA (US)(52) **U.S. Cl.**CPC ..... *A61B 5/14552* (2013.01); *H01L 31/0203*(2013.01); *H01L 31/02164* (2013.01); *H01L**31/173* (2013.01); *A61B 5/681* (2013.01);*A61B 5/7278* (2013.01); *A61B 2562/0242*(2013.01); *A61B 2562/04* (2013.01); *A61L**31/028* (2013.01)(72) Inventors: **Vivek Venugopal**, Santa Clara, CA  
(US); **Ueyn L. Block**, Menlo Park, CA  
(US); **Brian R. Land**, Woodside, CA  
(US); **Paul D. Mannheimer**, Los Altos,  
CA (US); **Albert E. Cerussi**, San Jose,  
CA (US)(21) Appl. No.: **17/018,850**(22) Filed: **Sep. 11, 2020****Related U.S. Application Data**(60) Provisional application No. 62/907,445, filed on Sep.  
27, 2019.**Publication Classification**(51) **Int. Cl.***A61B 5/1455* (2006.01)*H01L 31/0203* (2006.01)*H01L 31/0216* (2006.01)

(57)

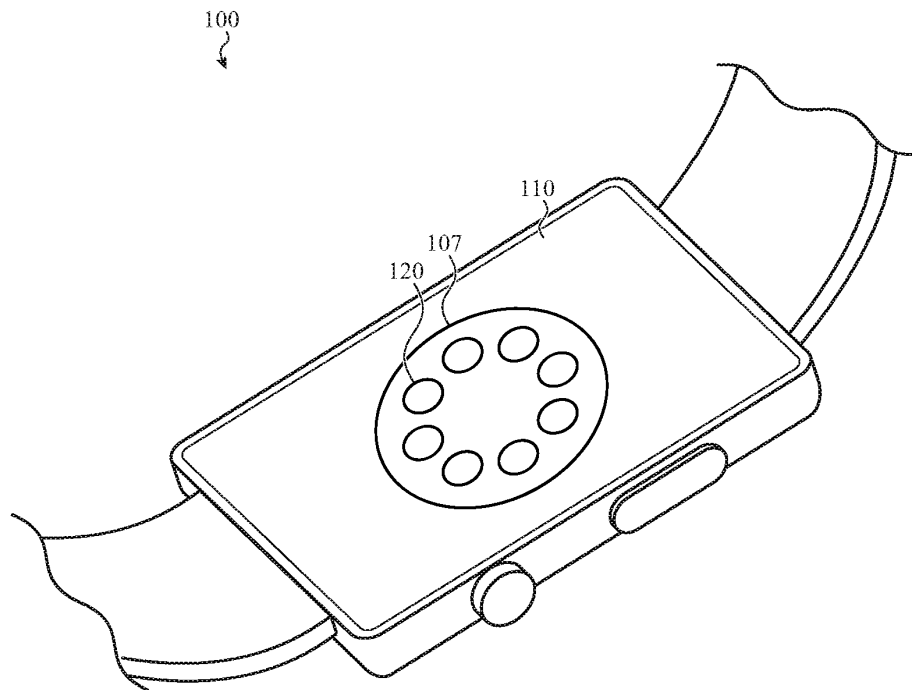
**ABSTRACT**

A wearable device is described. The wearable device includes a housing having a back cover, and an optical mask on first portions of the back cover. The back cover includes a set of windows, with a first subset of windows in the set of windows being defined by an absence of the optical mask on second portions of the back cover, and a second subset of windows in the set of windows being inset in a set of openings in the back cover. An optical barrier surrounds each window in the second subset of windows. A set of light emitters is configured to emit light through at least some of the windows in the set of windows. A set of light detectors is configured to receive light through at least some of the windows in the set of windows.





**FIG. 1A**



**FIG. 1B**

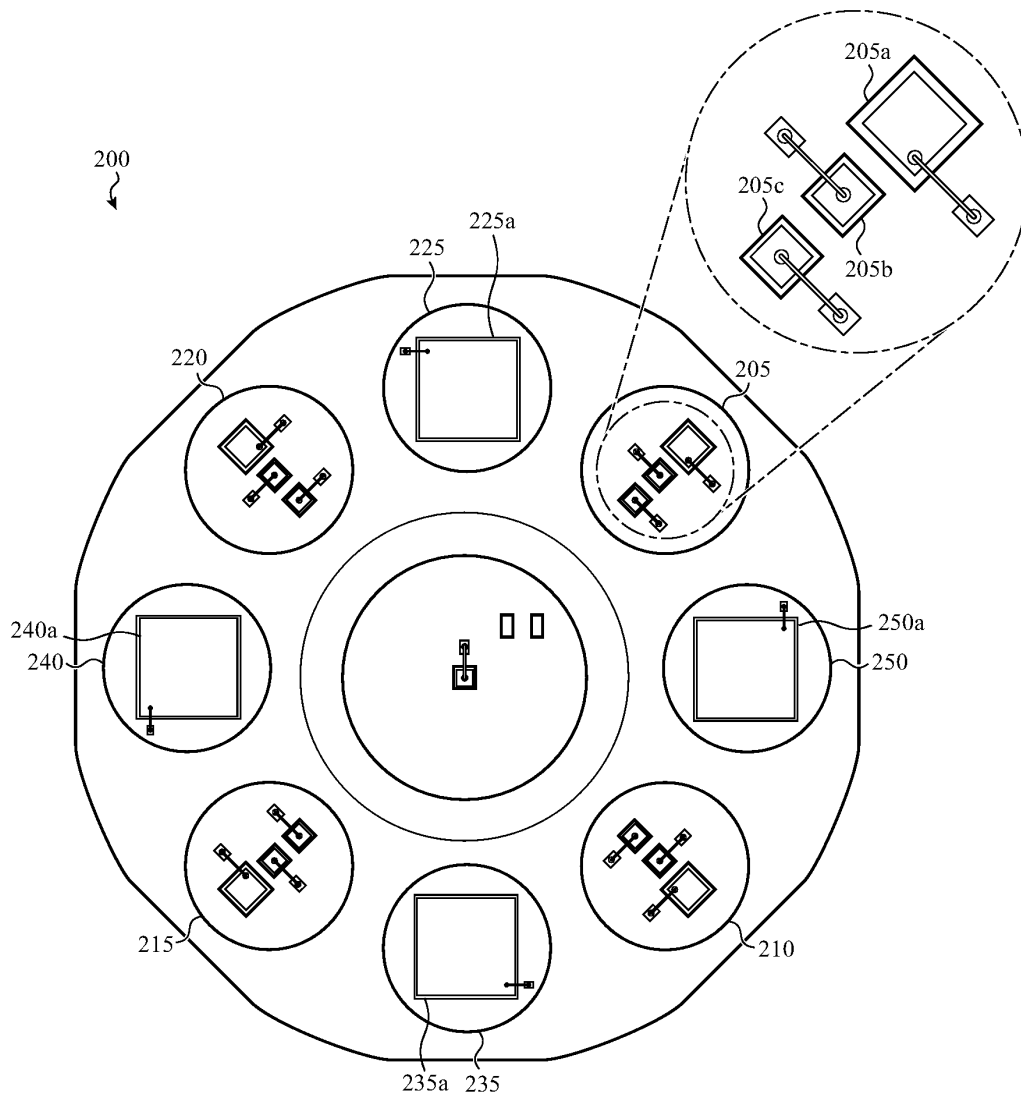
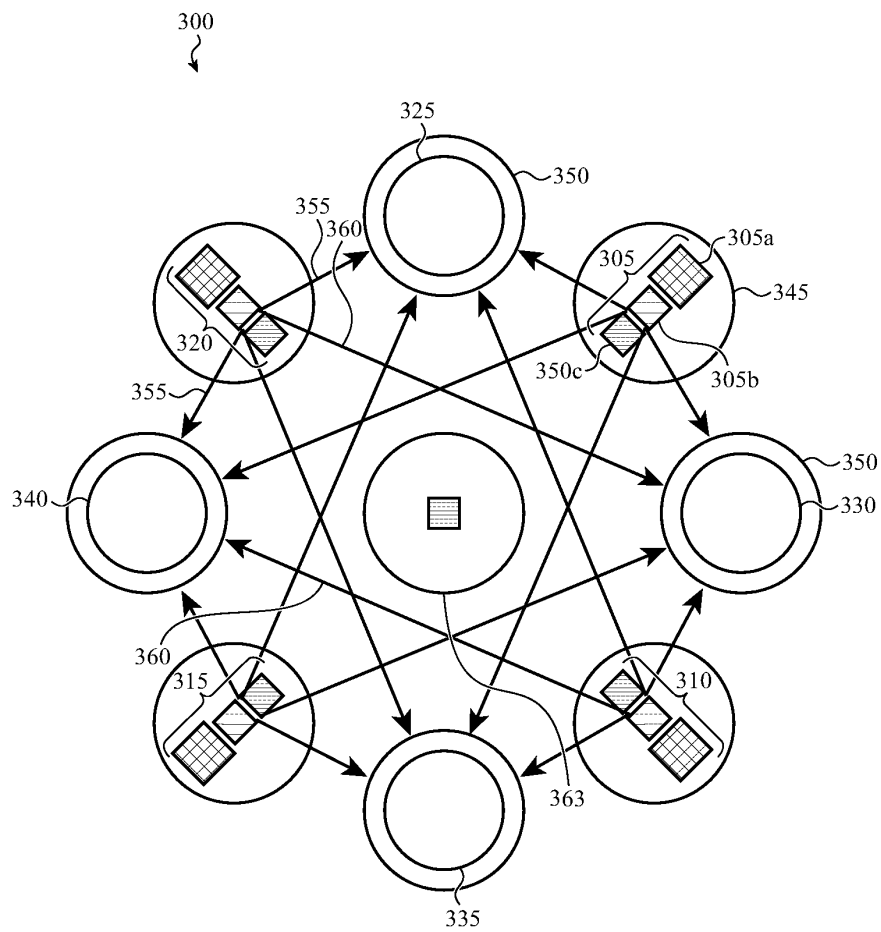


FIG. 2

**FIG. 3**

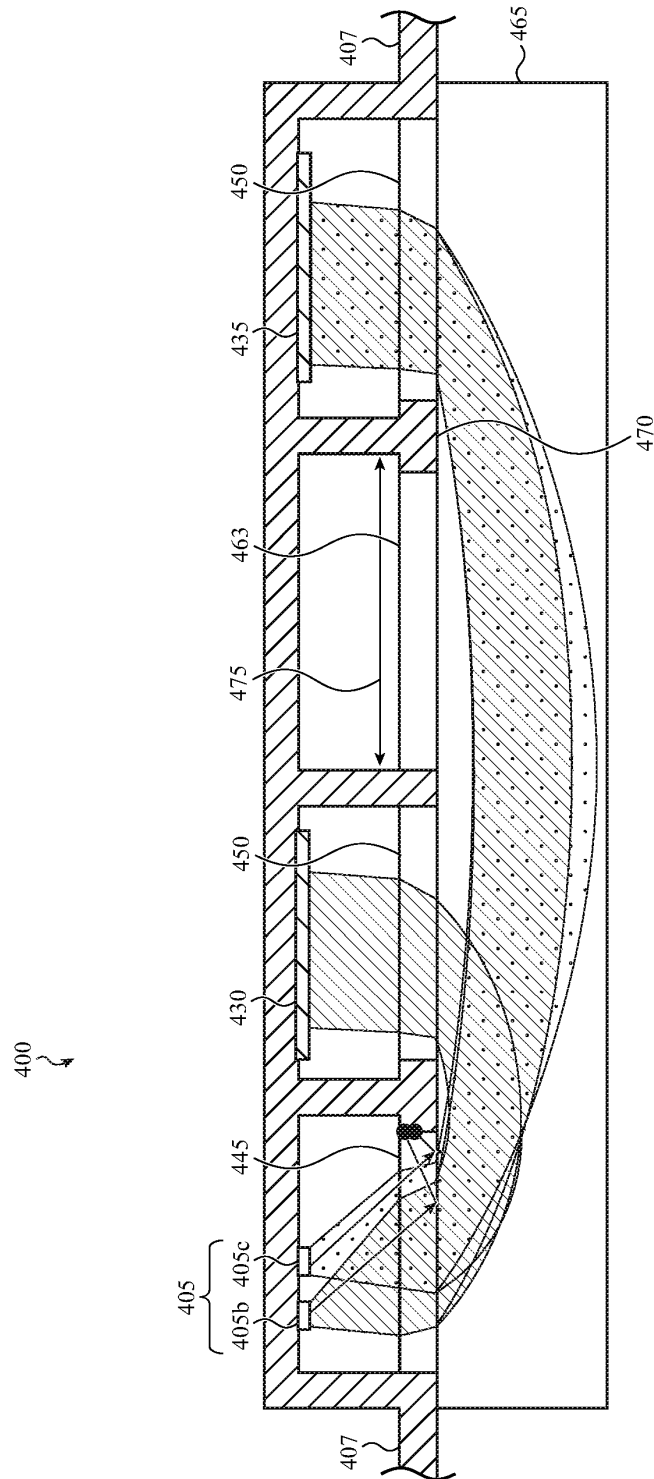


FIG. 4

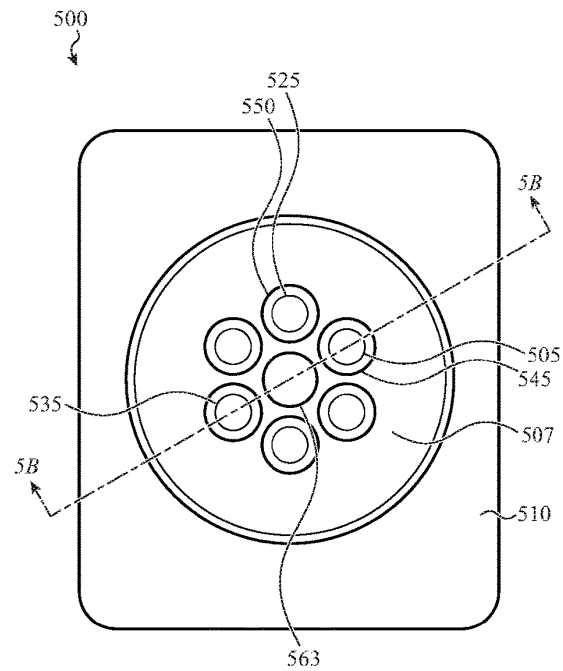


FIG. 5A

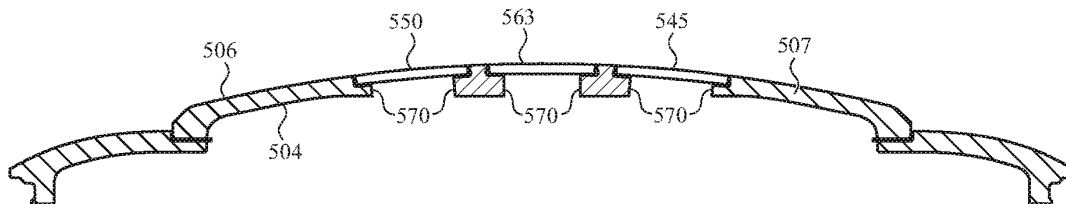
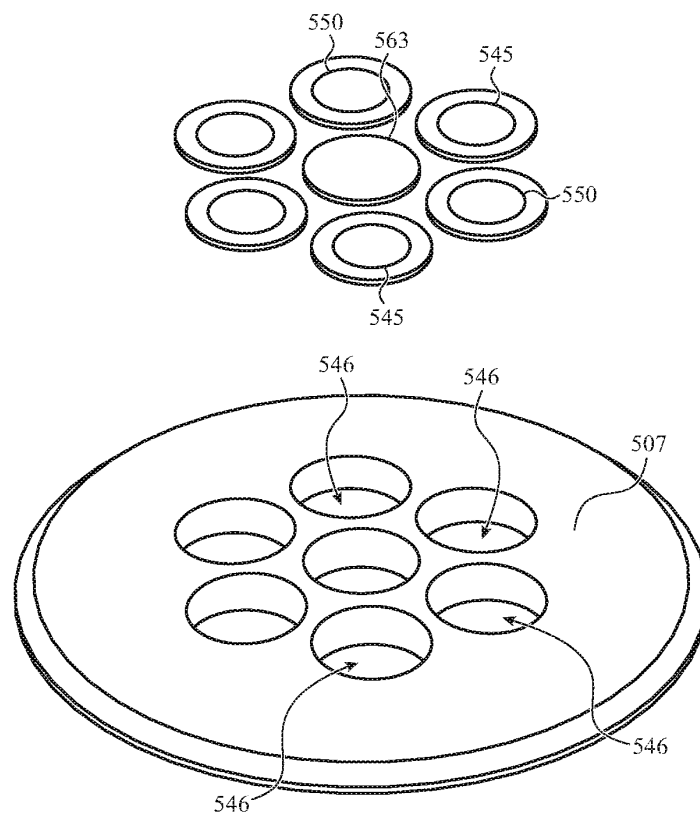
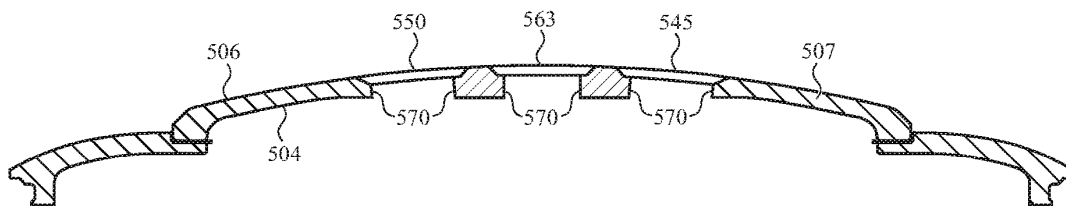


FIG. 5B





**FIG. 5C**



**FIG. 5D**

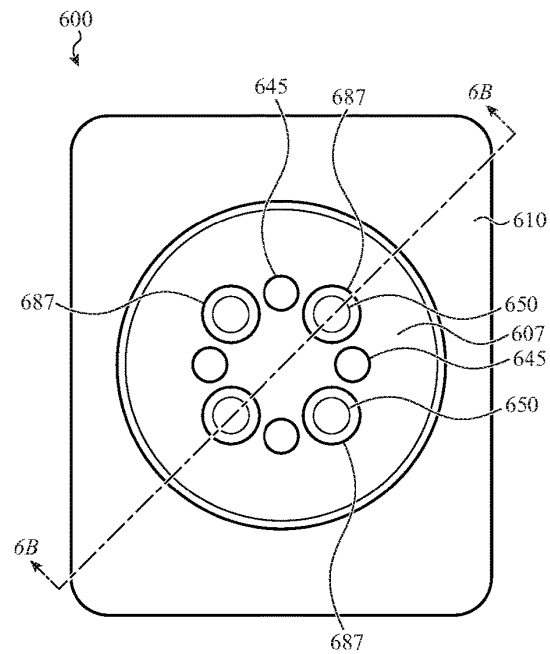


FIG. 6A

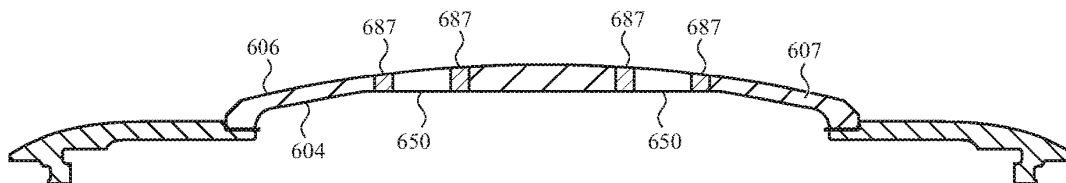
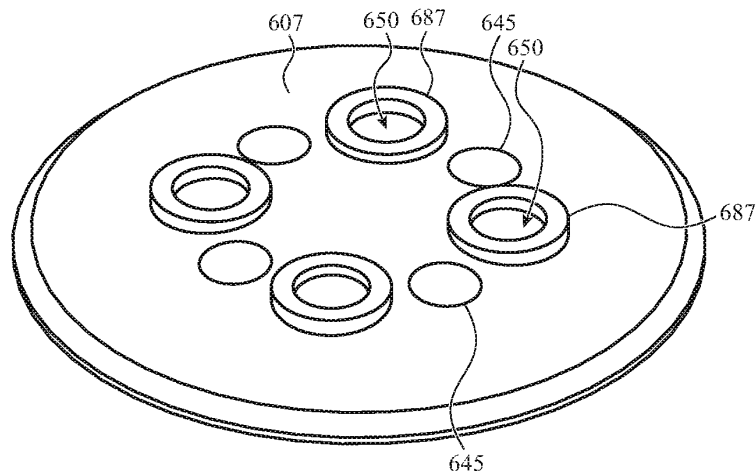
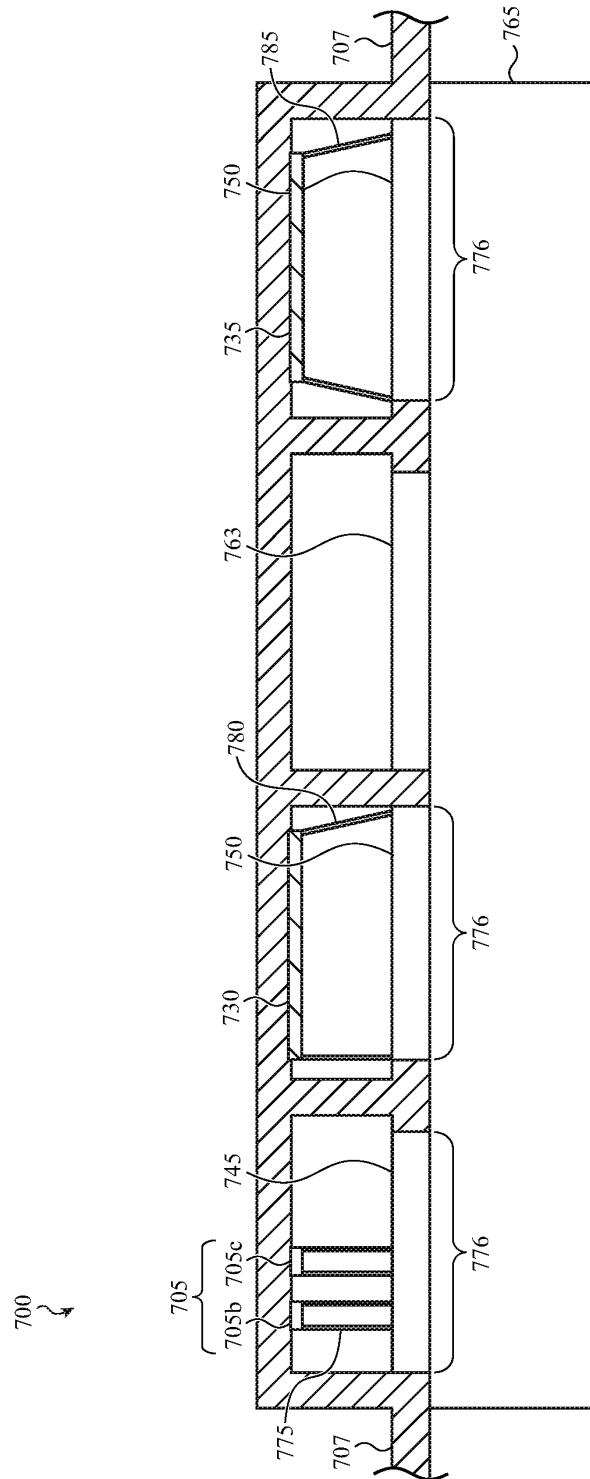
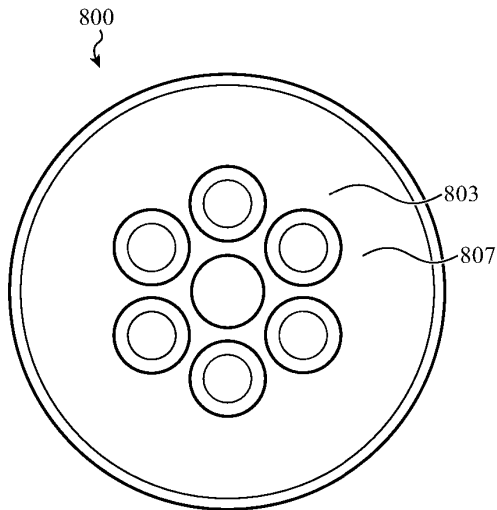


FIG. 6B

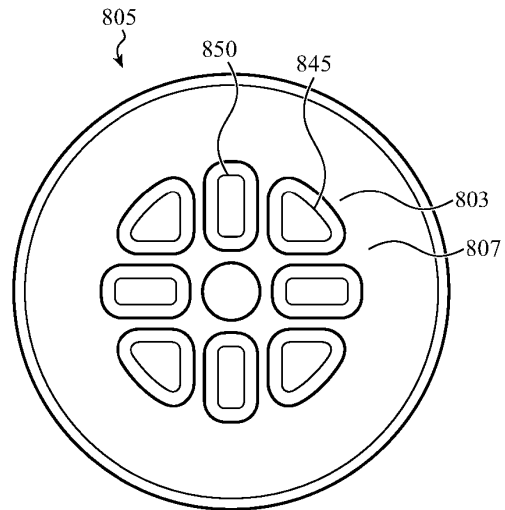


**FIG. 6C**

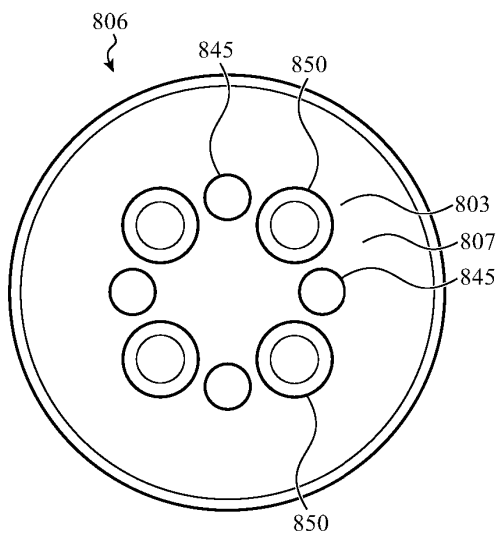




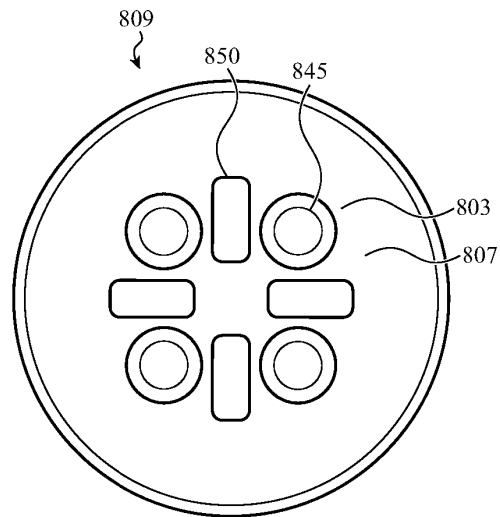
**FIG. 8A**



**FIG. 8B**



**FIG. 8C**



**FIG. 8D**

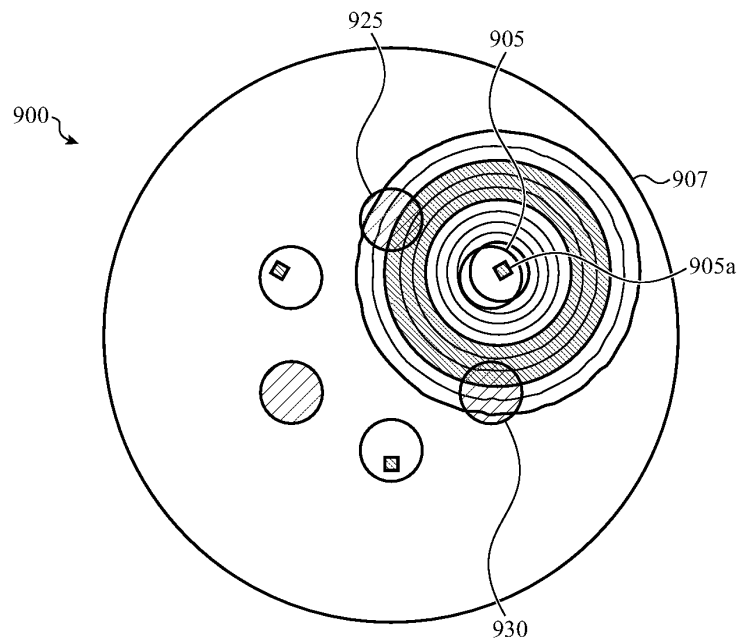


FIG. 9A

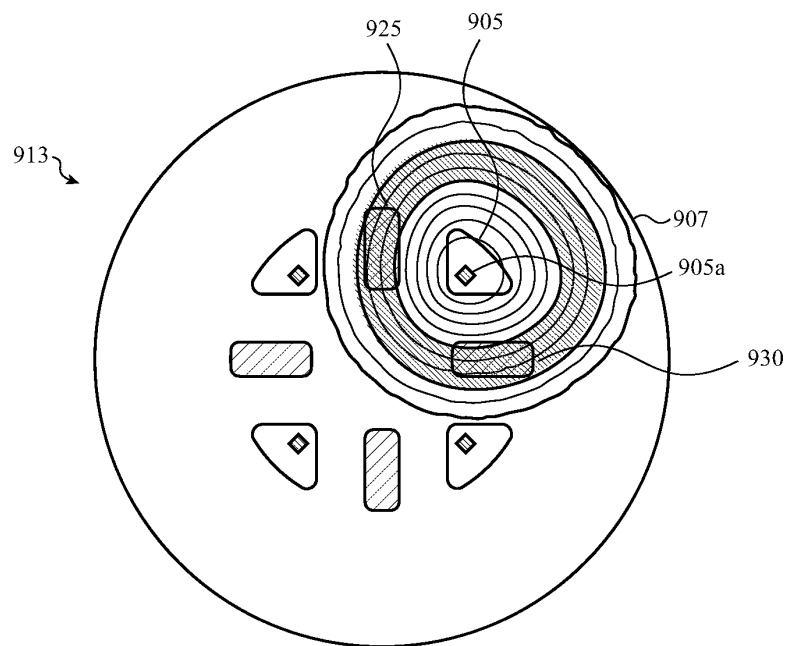
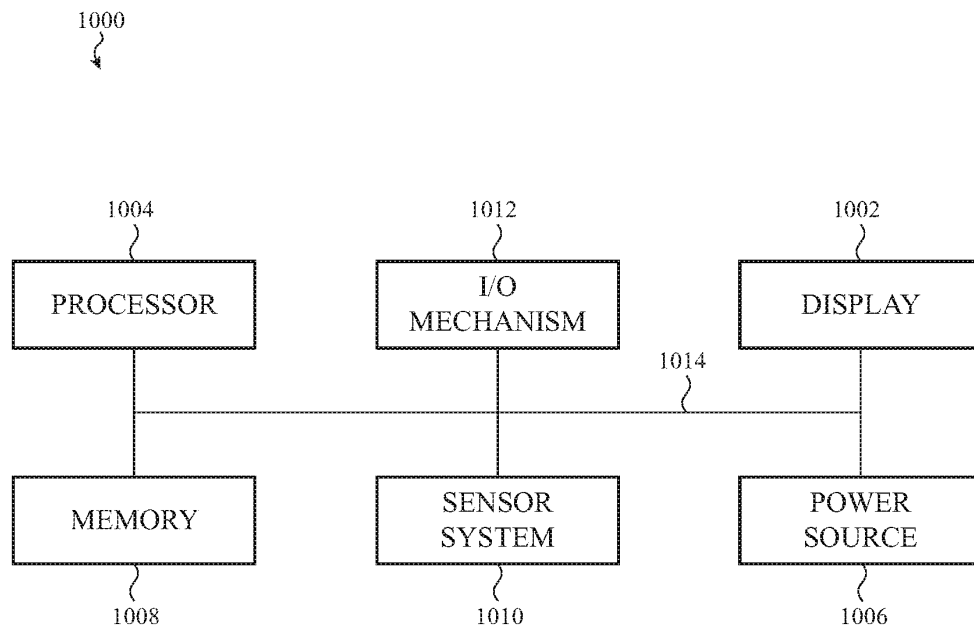


FIG. 9B



**FIG. 10**



US 2021/0093237 A1

Apr. 1, 2021

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## PHYSIOLOGICAL MONITORING SYSTEM FOR MEASURING OXYGEN SATURATION

### CROSS-REFERENCE TO RELATED APPLICATION

[0001] This application is a nonprovisional of and claims the benefit under 35 U.S.C. § 119(e) of U.S. Provisional Patent Application No. 62/907,445, filed Sep. 27, 2019, the contents of which are incorporated herein by reference as if fully disclosed herein.

### FIELD

[0002] Some of the described embodiments relate generally to physiological monitoring systems for measuring oxygen saturation and, more particularly, to reflective-type devices and systems for measuring oxygen saturation. Some of the described embodiments also or alternatively relate to emitting and receiving light through a housing of a wearable device.

### BACKGROUND

[0003] The use of technology in the medical profession and the general population to monitor a user's heart rate or other types of biometric information has increased with advances in sensing technology. In some examples, sensing devices (e.g., a chest strap heart rate monitor or watch) may be capable of measuring the heart rate of a person while they are exerting themselves in a physical activity such as running, and may alert the person if the heart rate varies outside of a desired range.

[0004] In some cases, sensing devices may be used for pulse oximetry, which may be an effective and quick way to monitor heart and lung function of a person. These pulse oximetry devices may be capable of evaluating the color of blood as the amount of oxygen carried by the hemoglobin may affect the color of blood. In some examples, a pulse oximetry device may be placed on a person's finger to measure the oxygenation of the person's blood. Generally, these device measurements may be reliable due to the homogeneous nature of the small tissue area over which the measurements are taken on the person.

### SUMMARY

[0005] Embodiments of the systems, devices, methods, and apparatus described in the present disclosure are directed to a wearable device used for pulse oximetry. Also described are systems, devices, methods, and apparatus directed to a wearable device having a set of openings and a set of ledges bordering the set of openings. The wearable device may include a set of windows in the openings and abutting the set of ledges. The wearable device may include a photodetector which may receive light through a window of the set of windows. The ledges and material around the perimeter of the windows may serve at least partially as a barrier to undesirable light being detected by the sensors, in that the windows may be at least partially isolated from unwanted light being sensed by the sensors.

[0006] In some examples, the present disclosure describes a wearable device that may include a housing having a back cover, and an optical mask (e.g., at least one of an ink, film, coating, or surface treatment) on first portions of the back cover. The back cover may include a set of windows, with a first subset of windows in the set of windows being defined

by an absence of the optical mask on second portions of the back cover, and a second subset of windows in the set of windows being inset in a set of openings in the back cover. An optical barrier may surround each window in the second subset of windows. A set of light emitters may be configured to emit light through at least some of the windows in the set of windows. A set of light detectors may be configured to receive light through at least some of the windows in the set of windows.

[0007] In some examples, the present disclosure describes a wearable device that may include a first set of emitters configured to emit a range of red light wavelengths, a second set of emitters configured to emit a range of infrared light wavelengths, and a set of detectors. Each detector in the set of detectors may be configured to detect amounts of at least the range of red light wavelengths and the range of infrared light wavelengths. The wearable device may also include a processor configured to operate the first set of emitters and the second set of emitters; receive indicators of the amounts of at least the range of red light wavelengths and the range of infrared light wavelengths detected by the set of detectors; and determine a blood oxygenation level using at least a subset of the indicators.

[0008] In some examples, the present disclosure describes a wearable device that may include a housing, a display viewable through a front side of the housing, and a skin-facing cover on a back side of the housing. The skin-facing cover may have an interior surface, an exterior surface, and a set of ledges bordering a set of openings. The set of openings may extend through the skin-facing cover from the interior surface to the exterior surface. The wearable device may also include a set of windows disposed in the set of openings and abutting the set of ledges, and a set of photodetectors disposed within the housing and configured to receive light through the set of windows.

[0009] In some examples, the present disclosure describes a wearable device. The wearable device may include a skin-facing cover. The skin-facing cover may include an interior surface; an exterior surface; and a set of ledges bordering a set of openings, the openings extending through the interior surface and the exterior surface; a set of windows disposed in the openings and abutting the set of ledges; and a photodetector disposed to receive light through a window in the set of windows. In some examples the skin-facing cover may be optically opaque. In some examples, the set of ledges may include a stepped ledge and/or the set of ledges may include a tapered ledge. In some examples, the skin-facing cover may be optically transparent and the set of windows may be optically transparent. In some examples, one or more ledges of the set of ledges may be coated with an optically opaque material, where the optically opaque material may be optically opaque ink. In some examples, one or more edges of one or more windows of the set of windows may be coated with an optically opaque material.

[0010] In still further examples, the photodetector may be a first photodetector and the window may be a first window, and the wearable device may further include: a second photodetector disposed to receive light through a second window of the set of windows; a first light emitter disposed to emit light through a third window in the set of windows, wherein the third window is closer to the first window than the second window; and each of the first photodetector and the second photodetector are configured to receive reflections or backscatters of the light emitted by the first light

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emitter. In some examples, the wearable device may further include a second light emitter disposed to emit light through a fourth window in the set of windows, wherein each of the first photodetector and the second photodetector is configured to receive reflections or backscatters of the light emitted by the second light emitter. In some examples, the first light emitter may be configured to emit red light, where each window in the set of windows may be optically transparent to at least a range of red and infrared light wavelengths; and each ledge of the set of ledges extends from an edge of one of the openings and in the approximate direction of a plane parallel to the interior surface, and each opening has a smaller diameter at the interior surface than at the exterior surface. In some examples, each window of the set of windows may be circularly shaped.

**[0011]** In some examples, the present disclosure describes a reflective sensing device, which may include: a first emitter configured to emit a range of red light wavelengths; a second emitter configured to emit a range of infrared light wavelengths; a first detector; a second detector, wherein the first detector and the second detector are both configured to detect at least the range of red light wavelengths emitted by the first emitter and the range of infrared light wavelengths emitted by the second emitter; and a processor configured to receive indicators of amounts of the detected range of red light wavelengths and the detected range of infrared light wavelengths received from each of the first detector and the second detector, the processor further configured to determine a blood oxygenation level using at least a subset of the indicators. In some examples, the first detector may detect the red light wavelengths emitted by the first emitter on a first optical path and the second detector may detect the red light wavelengths emitted by the first emitter on a second optical path, and the first and second optical path may be different lengths. In some examples, the reflective sensing device may further include: a third emitter configured to emit a range of green light wavelengths; and a third detector configured to detect at least the emitted range of green light wavelengths from the third emitter, wherein the processor is configured to receive the detected range of green light wavelengths from at least the third detector. In some examples, the processor may be configured to sum together indicators of amounts of detected wavelength ranges from the first detector, the second detector, and the third detector. In some examples, the first emitter, the second emitter, and the third emitter may emit light sequentially. In some examples, the processor may be configured to determine the subset of received red light and infrared light used to determined blood oxygenation, based at least in part on the received green light.

**[0012]** In some examples, the present disclosure describes a wearable device, which may include: a back cover including a set of windows disposed about a central portion of the back cover; a set of light emitters disposed under a first subset of the set of windows included in the back cover, the set of light emitters configured to emit at least red light and infrared light; a set of photodetectors disposed under a second subset of the set of windows included in the back cover, the set of photodetectors configured to detect at least the red light and the infrared light emitted by the set of light emitters. In some examples, the set of windows may abut a set of ledges that border a set of openings that extend through the back cover. In some examples, at least a first window of the first subset of windows may be located at a

different distance than a second window for the first subset of windows from the second subset of the set of windows.

**[0013]** In some examples, the present disclosure describes a reflective sensing device, which may include: a housing having a back cover; a set of emitters disposed within the housing and which may include: a first subset of emitters configured to emit red light through the back cover; and a second subset of emitters configured to emit infrared light through the back cover; a set of detectors disposed within the housing and configured to detect red light received through the back cover and infrared light received through the back cover; a set of optical barriers forming part of the back cover and extending through the back cover, the set of optical barriers configured to block light emitted by the set of emitters from impinging on the set of detectors before the emitted light passes through an exterior surface of the back cover.

**[0014]** In some examples, the reflective sensing device may further include: a processor which may be configured to determine a blood oxygenation of a user of the reflective sensing device, wherein the blood oxygenation is determined using amounts of reflected red light and reflected infrared light detected by the set of detectors. In some examples, the set of optical barriers may define optically closed walls around at least one opening of a set of openings in the back cover, where the openings extend through the back cover. In some examples, the set of optical barriers may include hollow sleeves disposed in the set of openings of the back cover of a wearable device. In some examples, at least one emitter may be positioned to emit light within an opening defined by one of the hollow sleeves. In some examples, at least one detector of the set of detectors may be positioned to receive light through an opening defined by one of the hollow sleeves and/or at least one of the hollow sleeves may have an outer perimeter wall coated with an opaque material. In some examples, the opaque material may be an opaque ink.

**[0015]** In still further examples, at least one of the hollow sleeves may have an inner perimeter wall coated with an opaque material. In some examples, the reflective sensing device may further include a set of windows which may be disposed in the set of openings of the back cover. In some examples, the set of windows may be optically transparent windows. In some examples, the back cover may be an optically transparent back cover. Additionally, in some examples, the set of optical barriers may reflect at least the range of red light wavelengths and may reflect at least the range of infrared light wavelengths. In some examples, the set of optical barriers may be optically opaque. In some examples, the set of optical barriers comprises black glass.

**[0016]** In some examples, the present disclosure describes a wearable device, which may include: a back cover having: a substrate defining part of an interior surface and an exterior surface of the wearable device; and a set of frits extending through the substrate from the interior surface to the exterior surface and defining part of the exterior surface of the back cover, wherein the frits of the set of frits have frit openings extending through the interior surface and the exterior surface; a set of windows disposed in the frit openings and defining part of the exterior surface of the back cover; and a set of photodetectors disposed to receive light through a subset of windows of the set of windows. In some examples, the subset of windows may be a first subset of windows; and the set of windows may further include a second subset of

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windows of the set of windows; and the wearable device may further include a set of emitters configured to emit light through the second subset of windows. In some examples, the back cover and the set of windows may be optically transparent. In some examples, at least one window of the set of windows has an outer diameter wall coated with an optically opaque material.

**[0017]** In some examples, the present disclosure describes a method of forming an optical barrier in a reflective sensing device, which may include: inserting a hollow cylinder into a back cover opening of a wearable device, wherein the hollow cylinder has a centrally located opening; fusing the hollow cylinder to the back cover to form a mechanical bond between materials of the hollow cylinder and the back cover; inserting an optically transparent window into the centrally located opening of the hollow cylinder; and fusing the optically transparent window and the hollow cylinder together to form a mechanical bond between materials of the hollow cylinder and the optically transparent window, where: the hollow cylinder may be an optically opaque material and which may form an optical barrier between light emitted by an emitter configured to emit light through the back cover and a detector which may be configured to receive light through the back cover and positioned on a same side of the back cover as the emitter. In some examples, the optically opaque material comprises black glass. In some examples, each of the back cover and the windows may be sapphire.

**[0018]** In some examples, the present disclosure describes a reflective sensing device, which may include: a housing; a first set of emitters which may be configured to emit infrared light through the housing; a second set of emitters which may be configured to emit red light through the housing; a first set of waveguides which may be configured to guide infrared light emitted by the first set of emitters toward the housing; a second set of waveguides which may be configured to guide red light emitted by the second set of emitters toward the housing; a set of detectors which may be configured to detect reflections or backscatters of the infrared light emitted by the first set of emitters and the red light emitted by the second set of emitters; and a processor which may be configured to determine a blood oxygenation of a user of the reflective sensing device, wherein the blood oxygenation is determined using amounts of reflected or backscattered red light and reflected or backscattered infrared light detected by the set of detectors. In some examples, the first set of waveguides may be internally reflective of infrared light and/or the second set of waveguides may be internally reflective of red light. In some examples, the first set of waveguides and the second set of waveguides may be solid material and/or the core of the solid material may be internally reflective of infrared light and red light.

**[0019]** In some examples, the reflective sensing device may further include: a set of windows, where the set of windows may include: four emitter windows which may be configured to allow infrared light and red light emitted by the first set of emitters and the second set of emitters to pass through the emitter windows; and four detector windows which may be configured to allow reflected infrared light and reflected red light to pass through the four detector windows and to the set of detectors. In some examples, the reflective sensing device may further include: a third set of emitters which may be configured to emit green light; a third set of waveguides which may be configured to guide green

light to a third set of windows of the set of windows; and the set of detectors further which may be configured to detect reflected or backscattered green light emitted by the third set of emitters.

**[0020]** In some examples, the present disclosure describes a wearable device, which may include: a back cover; a set of emitters which may be configured to emit light; a first set of waveguides optically coupled to the set of emitters and which may be configured to guide the emitted light through the back cover; and a photodetector of a set of photodetectors disposed to receive reflected or backscattered light emitted by the set of emitters. In some examples, at least a first waveguide of the first set of waveguides may be configured to guide light from a first set of emitters of the set of emitters, where the first set of emitters may be configured to emit red light. In some examples, at least a second waveguide of the first set of waveguides may be configured to guide light from a second set of emitters of the set of emitters, where the second set of emitters may be configured to emit infrared light.

**[0021]** In still further examples, the wearable device may further include: a second set of waveguides which may be configured to receive reflected red light and reflected infrared light. In some examples, the second set of waveguides may be configured to guide light to the set of detectors. In some examples, the first set of waveguides and the second set of waveguides may be hardened glass. In some examples, the second set of waveguides may be internally reflective of infrared light and red light. In some examples, the first set of waveguides may be internally reflective of red light and may be internally reflective of infrared light. In some examples, the wearable device may further include: a third set of emitters of the set of emitters, the third set of emitters which may be configured to emit green light, where the first set of waveguides and the second set of waveguides may be internally reflective of green light. In some examples, the first and second set of waveguides may be fiber optic waveguides.

**[0022]** In some examples, the present disclosure describes a reflective sensing device, which may include: a first emitter may be configured to emit a range of red light wavelengths; a second emitter may be configured to emit a range of infrared light wavelengths; a first detector; a second detector, where the first detector and the second detector may be both configured to detect at least the reflected range of red light wavelengths from the first emitter and on a first optical path, and the first detector and the second detector may be both configured to detect at least the reflected range of infrared light wavelengths from the second emitter and on a second optical path, where the first optical path and the second optical path may be different lengths. In some examples, the reflective sensing device may further include: a first waveguide which may be configured to guide emitted red light wavelengths; and a second waveguide which may be configured to guide emitted infrared light wavelengths. In some examples, the detected range of red light and infrared light wavelengths may be detected on a first and second optical path of different lengths which may provide a mapping of arterial or venous blood flow for pulse oximetry.

**[0023]** In addition to the exemplary aspects and embodiments described above, further aspects and embodiments will become apparent by reference to the drawings and by study of the following description.

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## BRIEF DESCRIPTION OF THE DRAWINGS

[0024] The disclosure will be readily understood by the following detailed description in conjunction with the accompanying drawings, wherein like reference numerals designate like structural elements, and in which:

[0025] FIG. 1A illustrates an example of a wearable device;

[0026] FIG. 1B illustrates an example of a wearable device;

[0027] FIG. 2 illustrates an example layout of emitters and detectors;

[0028] FIG. 3 illustrates an example layout of emitters and detectors;

[0029] FIG. 4 illustrates an example layout of emitters and detectors;

[0030] FIG. 5A illustrates an example of a back side of a wearable device;

[0031] FIG. 5B illustrates an example of a back cover of a wearable device from the side view;

[0032] FIG. 5C illustrates an example of a back cover of a wearable device;

[0033] FIG. 5D illustrates an example of a back cover of a wearable device from the side view;

[0034] FIG. 6A illustrates an example of a back side of a wearable device;

[0035] FIG. 6B illustrates an example of a back cover of a wearable device from the side view;

[0036] FIG. 6C illustrates an example of a back cover of a wearable device;

[0037] FIG. 7 illustrates an example of a back cover, emitters, detectors, and waveguides of a wearable device from the side view;

[0038] FIG. 8A illustrates an example of a back cover of a wearable device;

[0039] FIG. 8B illustrates an example of a back cover of a wearable device;

[0040] FIG. 8C illustrates an example of a back cover of a wearable device;

[0041] FIG. 8D illustrates an example of a back cover of a wearable device;

[0042] FIG. 9A illustrates a layout of a back cover of a wearable device;

[0043] FIG. 9B illustrates a layout of a back cover of a wearable device; and

[0044] FIG. 10 illustrates a sample electrical block diagram of an electronic device.

[0045] The use of cross-hatching or shading in the accompanying figures is generally provided to clarify the boundaries between adjacent elements and also to facilitate legibility of the figures. Accordingly, neither the presence nor the absence of cross-hatching or shading conveys or indicates any preference or requirement for particular materials, material properties, element proportions, element dimensions, commonalities of similarly illustrated elements, or any other characteristic, attribute, or property for any element illustrated in the accompanying figures.

[0046] Additionally, it should be understood that the proportions and dimensions (either relative or absolute) of the various features and elements (and collections and groupings thereof) and the boundaries, separations, and positional relationships presented between them, are provided in the accompanying figures merely to facilitate an understanding of the various embodiments described herein and, accordingly, may not necessarily be presented or illustrated to

scale, and are not intended to indicate any preference or requirement for an illustrated embodiment to the exclusion of embodiments described with reference thereto.

## DETAILED DESCRIPTION

[0047] Reference will now be made in detail to representative embodiments illustrated in the accompanying drawings. It should be understood that the following description is not intended to limit the embodiments to one preferred embodiment. To the contrary, it is intended to cover alternatives, modifications, and equivalents as can be included within the spirit and scope of the described embodiments as defined by the appended claims.

[0048] Generally, different types of biometric information may be monitored on a person, such as heart rate and/or blood oxygenation. The biometric information may be monitored using sensing devices that forego the need for performing invasive procedures on the person. This information may be monitored using sensing devices such as thermometers which may be placed in the ear or on the forehead of the person, or a heart rate and/or blood oxygenation device which may be placed on the index finger of the person. One characteristic of these devices is that they are pass-through measurement type devices. When employing these devices light may be emitted into one side of the finger or ear lobe and the light may be detected on the other side of the finger or ear lobe. The light may generally pass through approximately 0.5-1.0 cm of tissue before being detected. These sensing devices may be effective for use in a controlled environment, for example, during a medical examination. To measure the blood oxygenation of a person, a sensing device such as a pulse oximeter may be placed on the index finger of the person. The pulse oximeter may measure changes in the color of blood in a small tissue area, and accordingly may use a single emitter and single detector. Further, due to the small tissue area being measured, the tissue in the small area such as an index finger or ear lobe may be relatively homogenous, which may make the measurements reasonably reliable. The index finger or ear lobe may be confined areas and well-perfused tissue areas, which may additionally make the measurements reasonably reliable. Further, finger tips are well-vascularized and generally provide strong pulsatile light signals for pulse oximetry, which may also contribute to reasonably reliable measurements. Although these technologies may provide accurate measurements, these devices are not conducive to performing measurements while a user is moving or going about their daily routine. Accordingly, sensing devices such as heart rate monitors are being integrated into wearable devices so that a person may monitor biometric data such as heart rate on a daily basis and while engaging in various activities.

[0049] Some heart rate monitors are being incorporated in chest straps, watches, and other types of fitness bands that people may wear to monitor biometric data while performing daily activities, or to monitor and/or maximize performance while exercising, training, and/or racing. Also, in the case of a device worn on a wrist or strapped to a user's chest or forehead or elsewhere, the tissue depth or structures within the tissue may significantly limit the amount of light that passes through and exits the tissue. Sensors, such as heart rate monitors or pulse oximeters, may therefore be configured as reflective-type devices that emit light into one side of a wrist or limb and receive reflection of the light

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through the same side of the wrist or limb. Additionally, in the case of a device attached to a user via a band, it may be useful to implement a biometric sensor system as a reflective-type sensor to avoid having to incorporate part of the sensor system into the device's band (as might be required if the sensor system were implemented as a pass-through or transmissive type sensor system). Because these sensing devices may be integrated into devices such as wrist bands, watches, and smart watches, different challenges may arise due to the heterogeneous nature of the tissue in a person's wrist. For example, wrist tissue may include a dense network of blood vessels, tendons, ligaments, and bones all or some of which may reflect, scatter, and/or absorb light, thus making measurements at the wrist challenging.

**[0050]** Alternatively and as discussed herein, measurements may be implemented in an improved manner, thus improving the accuracy and reliability of the measurements. In some examples, the sensing device may be a wearable device such as a watch or smart watch which may be worn on the wrist of a person. The watch may include multiple emitters and multiple detectors to image and/or optically probe the wrist tissue, which may address the heterogeneous nature of the wrist tissue and provide accurate measurements by collecting light passing through multiple regions. Further, the watch may include multiple emitters and multiple detectors to sample light that has passed through multiple tissue regions, which may address the reduced vascular density and heterogeneous nature of the wrist tissue. By employing multiple emitters and detectors, different length light paths may propagate through the tissues and may ensure that light is traveling through tissue as opposed to simply reflecting off of the tissue surface. In some less desirable cases, light may reflect off of the tissue surface if the band which may secure the device to the user is not tight, tilted, or intentionally worn loosely. The multiple emitters and multiple detectors may provide sufficient data so that a processor may be able to identify false readings and ineffective or useless measurements from the data. In some examples, the signals from the detectors (e.g., indicators of amounts of detected light) may be summed prior to processing, and in some cases regions suspected of corrupted data may be excluded. Corrupted data may be due to crosstalk due to the watch lifting off of the user's skin and/or undue tissue heterogeneity.

**[0051]** In order for the light from the emitters to reach the wrist tissue of the person, windows may be provided in the internal or skin-facing side of the wearable device. The windows may also provide an aperture through which reflected and/or backscattered light from the wrist tissue may be detected by the detectors. The windows may be anchored in the back cover and may be a feature through which one or more wavelengths of electromagnetic radiation may propagate. Further, the windows may be disposed in openings that extend through the back cover and in some examples, the windows may be sapphire windows. These windows may be anchored in the skin-facing side of the wearable device in various ways which will be discussed in further detail herein, and in some cases may be mounted in or on a back cover which is also formed of sapphire. Further, the methods for securing the windows in the back cover of the wearable device may also include optical isolation methods to reduce and/or eliminate internal crosstalk between the emitters and detectors.

**[0052]** In some examples, the light may be emitted to reach the wrist tissue of the user via a waveguide. The

waveguide may guide the emitted light through the skin-facing cover or back cover and to the wrist tissue. Similarly, the reflected light may be received or detected via a waveguide which may guide the reflected light to the one or more detectors. The waveguides may guide the light and/or receive the reflected light through windows which may be anchored in the back cover. Alternatively, the waveguides may guide the light and/or receive the reflected light directly through the back cover via openings in the back cover, where no windows may be present in the back cover. The openings in the back cover may extend through the internal surface and the external surface of the back cover.

**[0053]** Described herein are various configurations for maximizing the use of the emitters and detectors to perform pulse oximetry. In some embodiments, the windows may be secured by employing methods that provide an optical barrier between the emitters and the detectors.

**[0054]** These and other embodiments are discussed below with reference to FIGS. 1A-10. However, those skilled in the art will readily appreciate that the detailed description given herein with respect to these Figures is for explanatory purposes only and should not be construed as limiting.

**[0055]** Directional terminology, such as "top", "bottom", "upper", "lower", "above", "below", "beneath", "front", "back", "over", "under", "left", "right", etc. is used with reference to the orientation of some of the components in some of the figures described below. Because components in various embodiments can be positioned in a number of different orientations, directional terminology is used for purposes of illustration only and is in no way limiting. The directional terminology is intended to be construed broadly, and therefore should not be interpreted to preclude components being oriented in different ways.

**[0056]** FIG. 1A illustrates an example of a wearable device 100. In some examples, the wearable device 100 may be configured to perform a number of biometric or physiological measurements of a user or person that may be wearing the wearable device 100. In the example of FIG. 1A, the wearable device 100 may include a reflective sensing device configured to perform pulse oximetry on the user wearing the wearable device 100.

**[0057]** FIG. 1A depicts one example of a wearable device 100, which may be worn on a wrist of a user and may be any type of watch, for example, a smart watch or a sport watch, or any type of biometric device, for example, a heart rate monitor, with a front side 105 and a back side 110. The back side 110 of the wearable device 100 will be discussed in further detail herein. In alternative embodiments, the wearable device may be configured to be worn on an arm, head, neck, thigh, torso, or other body part.

**[0058]** A user of the wearable device 100 may view a display of the wearable device 100 through the front side 105 of the wearable device 100. The display may be configured to display information such as the time, date, weather, and so forth. The display may also be configured to display biometric measurements or data (e.g., the user's heart rate or blood oxygenation) acquired by the reflective sensing device, which reflective sensing device may be at least partially visible on the back side 110 of the wearable device 100. The back side 110 of the wearable device 100 may be the skin-facing side, which may be adjacent to the skin of the user wearing the wearable device 100. In some examples, the back side 110 of the wearable device may or

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may not be in direct contact with the skin of the user wearing the wearable device **100**. The back side **110** will be discussed in further detail herein.

**[0059]** In some examples, the wearable device **100** may be a watch and a biometric device. The wearable device **100** may be configured to measure various biometric user data of the user wearing the wearable device **100** such as heart rate and blood oxygenation. Because the wearable device **100** may be worn on the wrist of the user, different factors may be taken into account than other types of biometric sensors or detectors.

**[0060]** Biometric sensor design may consider various factors such as whether to use optical or electrical sensors, ease of use, the environment in which the sensor may be used, battery and/or power consumption, accuracy of the measurements, wavelength of the emitter, size and form factor of the detector or sensor, any combination thereof, and so forth. The terms detector and sensor may be used interchangeably herein. Some biometric sensors may measure heart rate via a chest strap which may include two electrodes. The electrodes on the chest strap may contact the skin to measure the heart rate of the user. Electrical sensors may be used for chest straps due to the dynamic movement of the user and the various environments and body conditions in which the chest strap may be used, for example, extremely cold weather, very hot weather, sweat, salt water, chlorinated water, and so forth. Although the chest strap may be bulky, may be an extra element the user has to wear, and may have a limited battery life, the ability to perform accurate measurements in multiple environments while performing dynamic movement may outweigh the inconvenience of wearing the chest strap.

**[0061]** Other biometric sensors utilized by medical professionals may be used and/or worn on a finger of the user, or in some cases used on the ear or ear lobe of the user. Biometric sensors such as thermometers and pulse oximeters may be configured for use in small physical areas such as on an index finger and in or on ears, which are physical body locations with blood vessels such as veins, arteries, and capillaries close to the skin surface. The proximity of the blood vessels to the skin surface in the finger may facilitate accurate measurements when detecting a heart rate or blood oxygen level. Additionally, due to the small tissue area of use on a fingertip or in an ear, these biometric sensors may be useful for controlled environments, but not as useful when performing daily routine activities. Further, the small area of a fingertip or an earlobe may provide homogenous tissue for the sensor, thus allowing accurate data to be measured when taken in the small area.

**[0062]** Pulse oximeters may be capable of measuring the color of a person's blood and generally provide a quick and accurate way to monitor the heart and/or lung function of a person. As the oxygen level in a person's blood varies, the color of the person's blood may change. The pulse oximeter may detect or sense that change in color of the person's blood as it varies. Because the pulse oximeters used on finger tips or ears measure a small area, the sensing devices may use a single source or emitter for each corresponding wavelength and a single detector. For example, these pulse oximeters may use a source that emits red light and a source that emits infrared light and may sense the emitted light using a single detector capable of sensing both red and infrared light.

**[0063]** In FIG. 1A, the wearable device **100** may be worn on the user's wrist and because pulse oximetry is being performed via the wearable device **100** with emitters and detectors on the wrist, the measurements may become more complicated. Generally, wrist tissue is heterogeneous in the area where a watch is typically worn on the wrist and may have different vascular density than a fingertip or an earlobe or ear. The wrist may have bone, tendon, veins, and arteries from which the light from the sensor may be reflected, which may provide unpredictable results, and in some cases false measurements. Additionally, the wrist area over which the measurements may be taken is a larger area than a fingertip or an ear lobe, thus making providing more data, some of which may not be accurate data.

**[0064]** FIG. 1B illustrates an example of a wearable device **100**. Similar to FIG. 1A, the wearable device **100** may include a reflective sensing device configured to perform pulse oximetry on the user wearing the wearable device **100**. FIG. 1B depicts one example of the back side **110** of the wearable device **100** shown in FIG. 1A. In some examples, the wearable device **100** of FIG. 1B may be worn on a wrist of a user and may be any type of watch, for example, a smart watch or a sport watch, or any type of biometric device, for example, a heart rate monitor, with a front side **105** (as illustrated in FIG. 1A) and a back side **110**.

**[0065]** In FIG. 1B, the wearable device **100** includes a back cover **107** or skin-facing cover that forms part of a housing of the wearable device **100**. The wearable device **100** also includes windows **120** in the back cover **107**, which in some examples may be visible on the exterior surface of the skin-facing side of the wearable device **100**. The back cover **107** and/or windows **120** may be formed of sapphire, glass, plastic, or other materials. In some embodiments, some or all of the windows **120** may be sapphire windows that are mounted within (i.e., inset in) openings in a sapphire back cover **107**. Some or all of the windows may also be integral with the back cover **107** and defined by an absence of an optical mask (e.g., an ink (an optically opaque ink), film, coating, or surface treatment) on other portions of the back cover **107**. For example, the optical mask may be on first portions (e.g., non-window portions) of the back cover **107**, and absent from second portions of the back cover **107**. Some of the windows **120** may provide an aperture through which the emitters of a reflective sensor system (not shown in FIG. 1B) may emit light. The emitted light may pass into the tissue of the user and then may scatter, be absorbed, or reflect off of the tendons, bones, and blood vessels of the user. The reflected light from the arterial blood may be detected by the detectors of a reflective sensor system (not shown in FIG. 1B) incorporated into the wearable device **100**. Some of the windows **120** may provide an aperture through which the detectors (i.e., light detectors or photodetectors) may detect the reflected light from the tissue. The windows **120** may provide for good coupling between the windows **120** and the skin, which may ensure acceptable measurement accuracy. Further, the windows **120** may provide for optical isolation of the reflected light and methods of providing the optical isolation are discussed in further detail herein. In some embodiments, windows **120** over the emitters may be integral with the back cover **107** and windows **120** over the detectors may be inset within the back cover **107**.

**[0066]** In some examples, the exterior surface of the back side **110** of the wearable device **100** may be in close contact

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with the wrist of the user which may reduce air gaps between the windows **120** and the tissue of the user. Air gaps may reduce the accuracy of the detectors as some of the light reflected from the tissue may pass through air and some of the reflected light may not due to a tilt in the wearable device **100** which makes contact to the skin in some places but not in others, thus altering the optical path to the detector and possibly affecting the detector reading. Alternatively, the wearable device **100** may be in close contact to the tissue of the user and may be too tight, thus restricting blood flow of the user and affecting the detector readings. As discussed herein, multiple emitters and multiple detectors may be used to provide the blood oxygenation measurements. In using more than one emitter and detector, there may be multiple different optical path lengths and optical path directions between the emitters and detectors. These multiple optical path lengths and optical path directions may be used to compensate for the air gaps and such by selecting the appropriate path or paths which may provide meaningful information for use in determining blood oxygenation.

[0067] FIG. 2 illustrates an example layout **200** of emitters and detectors. In some examples, the layout **200** of emitters and detectors may be incorporated into some aspects of the wearable device **100** as described with reference to FIGS. 1A and 1B. In the example of FIG. 2, the layout **200** of emitters and detectors may be included in the wearable device to provide physiological and/or biometric measurements of the user wearing the wearable device **100** of FIGS. 1A and 1B.

[0068] By way of example and for purposes of description, the layout **200** of emitters and detectors may be located on the skin-facing side of the wearable device **100** as discussed with reference to FIGS. 1A and 1B. The layout **200** of emitters and detectors may be protected by a back or skin-facing cover (not shown in FIG. 2) with windows or apertures which is discussed in further detail herein.

[0069] As illustrated in FIG. 2, the layout **200** may include emitters positioned within various emitter windows **205**, **210**, **215**, and **220** (e.g., emitters **205a-c** positioned within emitter window **205**). FIG. 2 also shows detector **225a**, detector **235a**, detector **240a**, and detector **250a**. Emitters **205a-c** may include a green light emitter **205a**, an infrared light emitter **205b**, and a red light emitter **205c**. Similarly, each set of emitters positioned within the other emitter windows **210**, **215**, and **220** may include a green light emitter, an infrared light emitter, and a red light emitter. Although green light, infrared light and red light may be described as being emitted by the emitters herein, the green light may be understood to be electromagnetic radiation in the approximate range of green light wavelengths, the infrared light may be electromagnetic radiation in the approximate range of infrared light wavelengths, and the red light may be electromagnetic radiation in the approximate range of red light wavelengths. In some examples, the emitters may be a coherent light source such as a laser and/or laser diode, semi-coherent light source such as a light emitting diode or superluminescent diode, a non-coherent light source, or any other appropriate light emitting source. Additionally depicted in FIG. 2, each of the individual emitters and detectors (or photodetectors) may receive power and/or signaling via bond wires.

[0070] The detectors **225a**, **235a**, **240a**, and **250a** of windows **225**, **235**, **240**, and **250** of FIG. 2 may be electromagnetic radiation detectors. The terms detectors and sen-

sors may be used interchangeably herein. Each of the detectors in FIG. 2 may be configured to receive any of the emitted light from any of the emitters in emitter windows **205**, **210**, **215**, and/or **220**. The detectors **225a**, **235a**, **240a**, and **250a** may be configured to detect or receive light or photons and to convert the detected light/photons into an electrical current and/or electrical signal. Depending on the location of the emitter from which the detector receives the light, the detected light may have varying intensities due to various light scattering, absorption, and/or reflections by the wrist tissue and may be more or less easily detected by the detectors.

[0071] The detectors **225a**, **235a**, **240a**, and **250a** may detect any of the emitted green light, infrared light and/or red light emitted by the emitters in FIG. 2. Though the detectors **225a**, **235a**, **240a**, and **250a** may be described as detecting green light, infrared light, and red light, detecting the green light may be understood as detecting electromagnetic radiation in the approximate range of green light wavelengths, detecting the infrared light may be understood as detecting electromagnetic radiation in the approximate range of infrared light wavelengths, and detecting the red light may be understood as detecting electromagnetic radiation in the approximate range of red light wavelengths. In some examples, the detectors **225a** of FIG. 2 may be a photodiode, a photoconductor, or any other appropriate detector capable of sensing light at the appropriate wavelengths and intensities as described herein. As discussed herein, the detectors are described as receiving or detecting light emitted from the emitters, but it may be understood that the received or detected light is reflected light and/or back-scattered from the tissue. Further, the reflected and/or back-scattered light may include the emitted light that has passed through the tissue, light that has reflected off the tissue surface, or both. In some examples, the detectors may be at least partially optically isolated such that the detection of light directly from emitters is at least partially reduced or minimized, and in some examples, prevented. Optically isolating the detectors is discussed in further detail herein.

[0072] The emitters **205a-205c** of emitter windows **205**, **210**, **215**, and **220** and the detectors **225a**, **235a**, **240a**, and **250a** in the layout **200** of FIG. 2, may be disposed in a ring about the central portion of the back or skin-facing cover of the wearable device or watch. As illustrated in the example of FIG. 2, the emitters **205a-205c** of emitter windows **205**, **210**, **215**, and **220** may be arranged to alternate with the detectors **225a**, **235a**, **240a**, and **250a**. That is, emitter window **205** may be adjacent to detector window **225** and detector window **250**, emitter window **210** may be adjacent to detector window **235** and detector window **250**, and so forth. In some examples, due to the heterogeneous nature of the tissue in the wrist, the distance between the emitters and the detectors may be maximized by arranging the emitters and detectors in a ring or ring-like shape, to image and/or encompass as much of the wrist tissue as possible for any given watch size. In some examples, the configuration of emitters and detectors may be any other shape. Windows in a skin-facing cover disposed over the emitters and detectors may also be arranged in a ring and, in some cases, windows that are integral with the skin-facing cover may be interspersed with windows that are inset in the skin-facing cover (i.e., the different types of windows may be interspersed around the ring). In the example of FIG. 2, by surrounding a central region with emitters and detectors in a ring shape

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may increase the coverage area with fewer components. Due to the complexity of imaging and/or optically probing heterogeneous tissue, other factors may be considered for emitter and detector layouts, in addition to maximizing the distance between the emitters and detectors, such as false readings, emitter light clipping, path or channel lengths, battery life, power consumption, any combination thereof, and so forth. These factors are discussed in further detail herein.

[0073] As illustrated in FIG. 2, the layout 200 may be configured to accommodate eight windows, which may include four emitters and four detectors for measuring pulse oximetry. Although four emitters and four detectors may be discussed herein, in some examples, six windows, which may include three emitters and three detectors, may be used to accommodate the size of the watch. Any appropriate number of multiple emitters and multiple detectors may be used for pulse oximetry so long as the configuration and number of the emitters and detectors may be integrated into the wearable device. In some examples, using four emitters and four detectors may create sixteen channels or paths between emitters and detectors or may create up to sixteen different paths between emitters and detectors. Further, as the number of emitters and detectors increases, the less sensitive the pulse oximeter measurements may be to false and/or useless readings. Although an equal number of emitters and detectors are described herein, any number of emitters and detectors may be used, including an unequal number of emitters and detectors.

[0074] Each of the windows of FIG. 2 may include a green light emitter, an infrared light emitter, and a red light emitter. For example, the emitters may include a green light emitter 205a, an infrared light emitter 205b, and a red light emitter 205c. The other green, infrared, and red light emitters of FIG. 2 may be similarly numbered. In some examples, the green light emitter may be used to measure or monitor the heart rate of the user. Additionally, the green light emitter may be located on the outside diameter and the farthest away from the central portion (or center) of the wearable device. The green light emitter may be positioned on the outer diameter because the green light may be detected by either one or both of the two closest or adjacent detectors. Due to this localized sensing of the green light in this example, the distance between, for example the green light emitter 205a and the detectors 235a and 240a may not be relevant as the detectors 225a and 250a are the two detectors which may sense green light emitted from the green light emitter 205a. In some examples, it may be possible that the detectors 235a and 240a may detect green light emitted by the green light emitter 205a.

[0075] The infrared light emitters and the red light emitters may be detected by any or all of the detectors 225a, 235a, 240a, and 250a, regardless of how close or far the detector may be from the emitter. In some examples, the red light emitter may be positioned closer to the central portion (or center) of the wearable device than the infrared light emitter. The red light emitter may be located closer to the middle of the wearable device because generally, the red light may be absorbed more than the infrared light, thus the red light is more sensitive to clipping than the infrared light.

[0076] In FIG. 2, the emitting area of each of the emitters 205a-c of emitter windows 205, 210, 215, and 225 is depicted as square, but may be any appropriate shape that allows a suitable amount of light to be emitted by the emitter.

Similarly, the detecting area of the detectors 225a, 235a, 240a, and/or 250a is represented as square, but may be another shape or configuration that allows a suitable amount of light to be detected by the detector. Further, the individual emitters (e.g., light emitting diodes (LEDs)) which are depicted as square in FIG. 2 may be positioned within round apertures and the individual detectors which are depicted as square may also be positioned within round apertures. The emitters and detectors are also depicted as being approximately equidistant from one another, but may be located equidistant from one another, or may be located various distances from one another as appropriate. Additionally, should the distance between the emitters and detectors vary, the detecting angle between emitters and detectors may also vary from the layout 200 depicted in FIG. 2. The distance between the emitters and the detectors may be chosen to optimize battery life and power savings. In some examples, some of the emitters and detectors may be located closer together depending on the absorption and reflection properties of the wavelength of light. The shapes of the emitters and detectors and layout configurations are discussed in further detail herein.

[0077] In some examples of FIG. 2, the wearable device may include windows 205, 210, 215, and 220 or apertures through which the emitted light from the emitters may pass. Similarly, the windows 225, 235, 240, and 250 may also serve as an aperture through which light reflected and/or backscattered from the wrist tissue may pass back into the wearable device and be detected by the detectors. The windows 205, 210, 215, and 220 may be seated in a back cover of the wearable device. The back cover or skin-facing cover may be part of the exterior surface of the skin-facing side of the wearable device as discussed with respect to FIGS. 1A and 1B. In some examples, the windows may provide optical isolation for the detectors so that the detectors do not receive light directly from the emitters. The optical isolation via the windows and the back cover is discussed in further detail herein.

[0078] Although the windows 205, 210, 215, 220, 225, 235, 240, and 250 are circular in FIG. 2, this is for explanatory purposes and the windows may be any appropriate shape as discussed in further detail herein. Additionally, the windows are approximately the same size in FIG. 2 for explanatory purposes, but the windows may be the same size or may vary in size as appropriate.

[0079] FIG. 3 illustrates an example layout 300 of emitters and detectors. In some examples, the layout 300 of emitters and detectors may be incorporated into some aspects of the wearable device 100 as described with reference to FIGS. 1A-2. In the example of FIG. 3, the layout 300 of emitters and detectors may be included in the wearable device to provide physiological and/or biometric measurements of the user wearing the wearable device 100 of FIGS. 1A and 1B.

[0080] By way of example and for purposes of description, the layout 300 of emitters and detectors may be located on the back or skin-facing side of the wearable device 100 as discussed with reference to FIGS. 1A and 1B. The layout 300 of emitters and detectors may be protected by a back or skin-facing cover with windows or apertures (not shown in FIG. 3) which is discussed in further detail herein.

[0081] As illustrated in FIG. 3, windows 345 may include emitters 305a, 305b, and 305c. Similar to FIG. 2, each of the emitter windows may include the green light emitter, the infrared light emitter, and the red light emitter. For example,



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emitter 305 may include green light emitter 305a, infrared light emitter 305b, and red light emitter 305c. Additionally, in FIG. 3, the windows 350 may include detectors 325, 330, 335, and 340. Window 363 may be a window in the central portion of the back cover. The windows, emitters, and detectors, may each incorporate features of similar elements described in other embodiments.

[0082] Between each of the emitter windows 345 and detector windows 350 are multiple paths including short paths 355 and long paths 360 (i.e., for each emitter (or each detector), there are at least first and second optical paths (or light detection paths) having respective first and second lengths). Further, methods of mounting or inserting the detector windows 350 into the back cover may provide optical isolation such that stray light from the emitters will not be detected by the detectors. In some examples, the windows alone may not provide sufficient light blocking from the internal crosstalk of the reflective sensing device.

[0083] Each of the emitters 305, 310, 315, and 320 include short paths 355 and long paths 360 to each of the other detectors 325, 330, 335, and 340. For example, emitter 320 has a short path 355 to detector 325, a short path to detector 340, a long path to detector 330 and a long path to detector 335. The long paths and the short paths may provide a mapping of arterial or venous blood flow for pulse oximetry. Further, the long paths and the short paths may provide an array of potentially differing perspectives of the arterial or venous blood flow signals for pulse oximetry. Each of the detectors may be capable of receiving or detecting light from each of the emitters 305, 310, 315, and 320 and each wavelength of each of the emitters. For example, detectors 325, 330, 335, and 340 may each be capable of sensing green light, infrared light, and red light.

[0084] FIG. 3 depicts four emitters and four detectors, which may provide sixteen different optical paths between emitters and detectors. Although FIG. 3 and other examples discussed herein may use four emitters and four detectors, any number of emitter and detectors may be used as appropriate. For example, as shown in other embodiments herein, three emitters and three detectors may be used in the reflective sensing device and may provide nine optical paths or up to nine optical paths between the emitters and detectors. In some examples, the higher the number of paths, the less sensitive the measurements may be to erroneous data. With a greater number of measurements, it may be easier to verify data with redundant or consistent measurements and may also be easier to identify erroneous data by comparing outlying measurements or inconsistent data.

[0085] Additionally, the greater the distance between emitters and detectors, the greater amount of wrist tissue may be imaged and/or optically probed with the measurements. One or more of the path signals may be used to image and/or optically probe the wrist tissue, thus the number of emitters and detectors and the distance between emitters and detectors may be appropriately chosen to image and/or probe as much of the wrist tissue as possible for the corresponding size of the wearable device. In some examples, the higher the number of emitters and detectors, the greater the number of optical paths over which to probe and/or take measurements for imaging the wrist tissue. However, the number of emitters and detectors may also be considered when optimizing the appearance of the wearable device and accounting for battery life of the wearable device.

[0086] Although the reflective sensing device may have multiple emitters and detectors there may be a predetermined sequence for turning the emitters and detectors on and off. In some examples, emitter 305 may be turned on, but the emitter 305 may turn on the single green light emitter 305a. Continuing this example, the adjacent detectors, detector 325 and detector 330, may be turned on to detect a returned amount of the green emitted light. In other examples, emitter 305 may be turned on and the infrared light emitter 305b and the red light emitter 305c may be turned on to emit light and detectors 325, 330, 335, and 340 may be all turned on to detect a returned amount of the infrared and red light. Some embodiments may turn on emitters 305 and 315, or may turn on emitters 315 and 320, or may turn on all the emitters at once. The order in which the emitters may be sequentially turned on may be predetermined or may be random. In some examples, all the emitters and detectors may be turned on at the same time.

[0087] As previously discussed, the detectors 325, 330, 335, and 340 may sense an amount of returned light (e.g., reflected light and/or backscattered light) that has passed through the arterial blood of the user. The detectors may include additional associated circuitry which may be configured to process the detected light measurements into signals and may provide these electrical signals to a processor. In some examples, the detected light measurements may be from each detector individually, or may be aggregate measurements derived from two or more detectors. The processor may be configured to receive the signals (or indicators, or outputs) from one or more of the detectors. In some examples, the processor may be configured to receive signals from one or more of the emitters. Additionally, the processor may be further configured to determine a blood oxygenation level using at least a subset of the received signals (or indicators or outputs) and in some cases the received or detected light. In some examples, the processor may be configured to receive the signals (or indicators or outputs) representing a detected range of red light and infrared light wavelengths from at least a first detector and a second detector, for example detectors 325 and 330. The processor may then determine a blood oxygenation level using a subset of the signals (or indicators or outputs) representing the received range of red light wavelengths and the received range of infrared light wavelengths.

[0088] In some examples, the processor may be configured to select which of the detector measurements to use and may select a subset of the received detector measurements. Additionally or alternatively, the process may be configured to select for use the signals and/or measurements associated with one or more of the emitters. The processor may be configured to use various factors to select the subset of measurements such as determining erroneous outlying measurements or being able to detect false reading measurements that may appear to be useful measurements, but may not comply with the assumptions that were made for taking the measurements. The processor may utilize data received from multiple optical paths or channels and weigh various features to identify useful data—e.g., by analyzing multiple views and/or regions of the wrist tissue, obtained by acquiring measurements over multiple optical paths. In other examples, the processor may use all of the data received from the detectors. Further, in some cases, the measurement and/or signals received from the detectors may be weak signals. By choosing which of the detector measurements to

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use, the processor may select sufficiently strong signals, or in some examples may select multiple signals (e.g., amounts of detected light) to sum together. Additionally, the emitters and detectors may be located farther away from one another because the detector signals may be added together.

[0089] In the example of FIG. 3, an amount of the green light emitted by emitter 305a may be detected by the closest detectors, detector 325 and detector 330. As previously discussed and as illustrated in FIG. 3, the green light emitters 305a, 310a, 315a, and 320a may be located the farthest away from the central portion of the wearable device back cover. The green light emitters may be less sensitive to the location because the green light may be detected by the closest detectors. Additionally, by locating the green light emitters close to the detectors, the battery life and power savings of the wearable device may benefit. Generally, green light may be used for heart rate detection and monitoring when incorporated into a wearable device. In some embodiments, the detected green light may also be used to differentiate good detector readings from erroneous detector readings (i.e., the amounts of detected green light may be used to determine a subset of red light and infrared light measurements (or indicators) used to determine a blood oxygenation level).

[0090] FIG. 4 illustrates an example layout 400 of emitters and detectors. In some examples, the layout 400 of emitters and detectors may be incorporated into some aspects of the wearable device 100 as described with reference to FIGS. 1A-3. In the example of FIG. 4, the layout 400 of emitters and detectors may be included in the wearable device to provide physiological and/or biometric measurements of the user wearing the wearable device as discussed with respect to FIGS. 1A-3.

[0091] By way of example and for purposes of description, the layout 400 of emitters and detectors may be located on the back or skin-facing side of the wearable device 100 as discussed with reference to FIGS. 1A and 1B. The layout 400 of emitters and detectors may be protected by a back or skin-facing cover with windows or apertures which is discussed in further detail herein.

[0092] As illustrated in FIG. 4, the layout 400 may include a window 445 for the emitter 405 and windows 450 for the near detector 430 and the far detector 435. The optional window 463 may be a window over the central portion of the back cover 407 of the wearable device. The windows may be disposed in openings 475 in the back cover 407 and may sit on or abut ledges 470. Alternatively, some or all of the windows may be integral with the back cover 407 and defined by an absence of an optical mask (e.g., an ink (an optically opaque ink), film, coating, or surface treatment) on other portions of the back cover 407. For example, the optical mask may be on first portions (e.g., non-window portions) of the back cover 407, and absent from second portions of the back cover 407. In some cases, and by way of example, the window 445 for the emitter 405 may be defined by the absence of an optical mask (e.g., the ink, film, coating, or surface treatment) that surrounds the window 445, and the windows 450 for the near detector 430 and the far detector 435 may sit on or abut ledges 470. The openings in the back cover and the ledges are discussed in further detail herein. The back cover 407 and/or windows 445, 450, 463 may be formed of sapphire, glass, plastic, or other materials.

[0093] In some cases, the emitter 405, the near detector 430, and the far detector 435 may be mounted to a printed circuit board (PCB), and the PCB may be attached to the back cover 407 by one or more components that form a set of optical barriers (or walls) between the PCB and the back cover 407. In these cases, the back cover 507, in combination with the PCB and one or more components that form the set of optical barriers (or walls), may define different cavities in which the emitter 405, the near detector 430, and the far detector 435 are separately housed.

[0094] The windows of FIG. 4 may form a surface with the back cover and the back cover 407 may be adjacent to the wrist tissue 465. The emitter 405 may include an infrared light emitter 405b and a red light emitter 405c. The light from the infrared light emitter 405b and the red light emitter 405c may pass into the tissue 465. The light reflected from the arterial blood flood and/or that has passed through a user's arterial blood and/or tissue 465 may pass through the windows 450 to the near detector 430 and the far detector 435. As previously discussed, the near detector 430 and the far detector 435 may be configured to receive or detect light from any of the emitters and to receive or detect reflected green light, infrared light, and/or red light. The ledges 470 may serve at least partially as optical isolators between the emitter window(s) and the detector windows which will be discussed in further detail herein.

[0095] As depicted in FIG. 4, the emitter 405c may emit red light through the window 445. The red light may pass through the window 445 to the tissue 465. The red light may reflect off a first area of tissue and back through the window 450 to be received or detected by the near detector 430. Additionally, the red light may reflect off a second area of tissue and back through the window 450 to be received or detected by the far detector 435. Further illustrated in FIG. 4, the red light reflected off the first area of tissue may not penetrate as deep into the tissue as the red light reflected off the second area of tissue. By placing the emitter and the detector farther away from one another, the light may penetrate different depths into the tissue, thus providing a more thorough image mapping and/or probing of the wrist tissue. Red light from emitter 405b may also enter the window 445 at such an angle that it may not be able to pass through the window due to total internal reflection (TIR). As shown in FIG. 4, the red light may reflect off of the external surface of the window towards the skin and reflect back into the window. The reflected red light may not be detected by the detector 430 since the reflected red light may be absorbed by the barrier or ledge 470 separating window 445 from window 450. The barrier or ledge 470 may isolate light emitted directly from the emitter from being detected by the detector, thus preventing undesirable internal crosstalk.

[0096] The light emitted from infrared light emitter 405b may pass through window 445 and enter the skin 465. The infrared light may reflect off of the arterial vessels in the skin 465 and may pass through window 450. The infrared light may then be sensed by the far detector 435. In the example of FIG. 4, the infrared light may not be received by the near detector 430. As illustrated, some of the emitted infrared light may not pass through the window 445 due to the angle at which it is emitted and may instead be reflected off of the window due to TIR. This infrared light may reflect off of the window and back into the window. The emitted infrared light reflected off the window and not the tissue, may not be detected by the detector 430 as it may be blocked by the

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optical barrier or ledge 470. The optical barrier or ledge 470 may isolate light which may be emitted at certain angles within the window 445 and at least partially reduce or prevent internal crosstalk and may prevent light emitted by the emitter from being sensed directly by a sensor without passing through the user's tissue first. In some examples of FIG. 4, infrared light may be reflected, scattered and/or backscattered out of the tissue and into the near detector 430. Although not depicted in FIG. 4, red light emitted by red light emitter 405c may be reflected, scattered and/or backscattered out of the tissue and into either one of the detectors 430 and detector 435. Similarly, infrared light emitted by infrared light emitter 405b may be reflected, scattered and/or backscattered out of the tissue and into either one of the detectors 430 and detector 435. The method of forming these windows with optical barriers via ledges 470 and other methods of providing optical isolation within the windows are discussed in further detail herein.

[0097] Each of FIGS. 5A-5D show a different view of the back cover and/or back side of the wearable device as previously described with reference to FIGS. 1A-4. FIG. 5A illustrates an example 500 of a back side 510 of a wearable device. In some examples, the back side 510 may be incorporated into some aspects of the wearable device 100 as described with reference to FIGS. 1A-4. In the example of FIG. 5, the back side 510 may be incorporated in the wearable device to provide physiological and/or biometric measurements of the user wearing the wearable device as discussed with respect to FIGS. 1A-4. As illustrated in FIG. 5A, the back side 510 of the wearable device may include the back cover 507. The back cover 507 may have six inset windows disposed about a central portion (or central window 563) of the back cover 507. The windows 545 may provide apertures through which emitters may emit light and the windows 550 may provide apertures through which detectors may detect light reflected off of a user's arterial blood flow and/or may detect backscattered light that has passed through a user's arterial blood. The windows may be inset into openings that extend through the back cover 507. Although the back cover 507 may include inset windows, the windows may form a smooth surface with the back cover 507.

[0098] FIG. 5B illustrates an example elevation of a back cover 507 of a wearable device. In some examples, the back cover 507 may be incorporated into some aspects of the wearable device 100 as described with reference to FIGS. 1A-5A. In the example of FIG. 5B, the back cover 507 may be incorporated in the wearable device to provide physiological and/or biometric measurements of the user wearing the wearable device as discussed with respect to FIGS. 1A-5A.

[0099] As illustrated in FIG. 5B, the side view may be a cross section toward the middle of the back side of the wearable device as depicted in FIG. 5A. The back cover 507 may include six peripheral windows disposed around a central portion of the back cover 507. In some embodiments, the central portion may include an optional center window. As previously mentioned, any appropriate number of windows may be used and six windows are used for explanatory and discussion purposes only. Window 545 may provide an aperture through which an emitter may emit light and window 550 may provide an aperture through which a detector may detect light reflected off of and/or backscattered from the user's tissue. Window 563 (as illustrated in

FIGS. 5A, 5B, and 5C) may be in a central portion (or center) of the wearable device and is optional. In some examples, window 563 may be employed to enable an optical sensor to detect whether the wearable device is contacting a user's skin, or to monitor a user's heart rate, or for other purposes. For example, an IR LED or other emitter may in some cases emit IR light through a central window, and an IR detector may detect a portion of the emitted IR light that is returned through the central window after reflecting or scattering off of a user. The returned portion of the emitted IR light may be used to determine whether the back cover is or is not adjacent a user's wrist (or is no longer adjacent a user's wrist), or the returned portion of the emitted IR light may be analyzed to determine the user's heart rate. In some cases, a central window, and/or optical sensing through a central window, may be incorporated into any of the device embodiments described herein.

[0100] In FIG. 5B the back cover 507 may have an internal surface 504 which may be internal to the wearable device and an external surface 506 which may be external to the wearable device. Further, the back cover 507 may include a substrate which may define at least part of the internal surface 504 and the external surface 506 of the wearable device. The external surface 506 may be the surface which may come into contact with the skin of the user wearing the wearable device. The back cover 507 or skin-facing cover may have openings which may extend through the back cover, for example the openings may extend through the internal surface and the external surface of the back cover 507. The back cover 507 may also include a set of ledges 570 which may border the openings as illustrated in FIG. 5B. In some examples, the ledges 570 may be stepped ledges, the ledges may extend entirely around the openings as shown and discussed with respect to FIGS. 5A-5D, or the ledges may be positioned at select angular extents about the openings, or other appropriate shapes or gradients as discussed herein. The windows may be disposed in the openings and may abut the ledges 570. The windows may be bonded in place to the back cover 507 and also to the ledges, which may secure the windows into place such that the windows may not be displaced or become tilted in the openings of the back cover 507. The windows may be bonded using any appropriate method such as an adhesive, melting, and so forth. In some examples, the entire back cover 507 may be optically opaque or the entire back cover 507 may be optically transparent. The back cover 507 may be optically opaque or transparent to the light emitted and/or detected or received by the wearable device.

[0101] In some examples of FIG. 5B, the ledges 570 may extend into the openings of the back cover 507. The ledges may extend into the openings to provide an edge on which the windows may rest. The ledges may provide a protruding edge on which the windows may sit. The ledges may ensure that the windows do not fall through the back cover and into the internal part of the wearable device. These ledges may be positioned adjacent to or near the internal surface of the back cover. Alternatively, the ledges may be adjacent to or near the external surface of the back cover so that the windows may be inserted from the outside or external surface of the back cover.

[0102] In some examples, the back cover 507 with the ledges may be an optically opaque material and the windows may be optically transparent. As used herein, optically opaque may not block 100% of all light across all wave-

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lengths, and may instead block a targeted wavelength of light which may be appropriately attenuated. In this example, the ledges may provide at least some optical isolation for the detectors so that stray light from the emitters may not be received at the detectors. Within a certain range of angles, light leaving the emitters may reflect off of the windows back toward the detector instead of passing through the window and into the tissue. Without optical isolation, this light that reflects off of the windows may be received by the detectors and may provide an erroneous measurement. With optical isolation, the light that reflects off of the windows and back towards the detector may be prevented from reaching the detector by the optically opaque ledge that optically isolates the detector. In some examples, the windows over the detectors may have optical barriers, while in other examples, the windows over the emitters may have optical barriers, and in further examples, the windows over both the emitters and the detectors may have optical barriers. In some examples, the optical barrier may be formed by coating the sides of the openings and/or the sides of the windows (e.g., surrounding the openings or windows) with an optically opaque ink or other material that is optically opaque to the emitted and detected light. Additionally or alternatively, the optical barrier may be formed by one or more of an ink, film, coating, or surface treatment disposed between a window and its respective opening (or ledge). The ink, film, coating, or surface treatment may be formed on, or applied to, the window or the opening (or ledge) before the window is abutted to and attached to the opening (or ledge).

[0103] In some examples, the detectors may detect a specific range of wavelengths, such as IR wavelengths. In this example, the optical barrier or optically opaque material may block the specific range of wavelengths that the detector detects (so that the emitted wavelengths are not detected by the detector without first passing through the back cover 507); or the optical barrier may block all wavelengths of light; or the optical barrier may block at least the range of IR wavelengths as well as some range on both sides of the IR wavelengths.

[0104] In some embodiments, the back cover 507 and/or windows 545, 550, 563 may be formed of sapphire, glass, plastic, or other materials. Although the windows may be optically transparent, in some examples the distance between the ledges may at least partially determine the size of the apertures through which light may pass. As previously discussed, the windows may abut the ledges and the ledges may be optical barriers between the emitters and the detectors. The ledges may have protruding edges for the windows to sit upon, thus the distance between the inner side of the ledges may be smaller than the openings and/or the windows. Accordingly, the area through which light may pass may be smaller than the openings in the back cover and instead may be the inner distance between the ledges.

[0105] FIG. 5C illustrates an example of a back cover 507 of a wearable device. In some examples, the back cover 507 may be incorporated into some aspects of the wearable device 100 as described with reference to FIGS. 1A-5B. In the example of FIG. 5C, the back cover 507 may be incorporated in the wearable device to provide physiological and/or biometric measurements of the user wearing the wearable device as discussed with respect to FIGS. 1A-5B.

[0106] As illustrated in FIG. 5C, the perspective view may be an example of the back cover 507 of the wearable device

as depicted in FIGS. 5A and 5B. The back cover 507 may include six windows 545, 550 disposed around a central portion (or optional central window 563) of the back cover 507. As previously mentioned, any appropriate number of windows (such as eight windows) may be used and six windows are used in this figure for explanatory and discussion purposes only. Windows 545 may provide an aperture through which an emitter may emit light and windows 550 may provide an aperture through which a detector may detect light reflected off of and/or backscattered from the user's tissue. Window 563 may be in the central portion (or center) of the wearable device. The back cover 507 and/or windows 545, 550, 563 may be formed of sapphire, glass, plastic, or other materials.

[0107] The back cover 507 may include openings 546 that extend through the back cover. The openings 546 may include ledges which may be stepped, tapered, cupped, or any other appropriate profile to at least partially support the window in the back cover 507. In some examples, the ledges may be tapered, and the taper may be a shallow taper as illustrated in FIG. 5D. In still other examples, the taper may extend through the openings of the back cover 507. In this example, the window may be the depth of the back cover 507.

[0108] In some examples, the ledges 570 may determine the size of the aperture through which light may pass or be detected. The windows 545, 550 may rest on or at least be partially supported by the ledges 570 and the windows 545, 550 may be optically transparent so that light may pass through or be detected through the windows 545, 550. In some examples, the back cover 507 may be optically opaque.

[0109] In other examples, the back cover 507 may be optically translucent or transparent and the windows 545, 550 may be optically translucent or transparent. In this example, the optically transparent back cover 507 may include ledges 570, but the ledges 570 may be coated with an optically opaque material such as ink to provide light blocking or optical isolation between the emitters and the detectors. Additionally, the ledges 570 may be optically transparent and the edges of the windows 545, 550 may be coated with an optically opaque ink. In yet another embodiment, both the ledges 570 and the edges of the windows 545, 550 may be coated with an optically opaque ink to provide the optical barrier between the emitters and the detectors.

[0110] FIG. 5D illustrates an example side view of a back cover 507 of a wearable device. In some examples, the back cover 507 may be incorporated into some aspects of the wearable device 100 as described with reference to FIGS. 1A-5B. In the example of FIG. 5D, the back cover 507 may be incorporated in the wearable device to provide physiological and/or biometric measurements of the user wearing the wearable device as discussed with respect to FIGS. 1A-5C.

[0111] As illustrated in FIG. 5D, the view may be an example of the back cover 507 of the wearable device as depicted in FIG. 5C. Similar to FIG. 5B, FIG. 5D illustrates the ledges 570 on which the windows 545, 550 may rest. The ledges 570 of FIG. 5D may be tapered as opposed to the stepped ledges of FIG. 5B.

[0112] Each of FIGS. 6A-6C show a different view of the back cover on the back side of the wearable device as previously described in FIGS. 1A-5D. FIG. 6A illustrates an example 600 of a back side 610 of a wearable device. In

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some examples, the back side 610 may be incorporated into some aspects of the wearable device 100 as described with reference to FIGS. 1A-5D. In the example of FIG. 6A, the back side 610 may be incorporated in the wearable device to provide physiological and/or biometric measurements of the user wearing the wearable device as discussed with respect to FIGS. 1A-5D.

[0113] As illustrated in FIG. 6A, the back side 610 of the wearable device may include the back cover 607. The back cover 607 may have four to eight inset windows which may provide sixteen optical sensing paths or channels. The windows 650 may provide apertures through which detectors may detect light reflected off of a user's arterial blood flow and/or may detect backscattered light that has passed through a user's arterial blood. The back cover and/or windows may be formed of sapphire, glass, plastic, or other materials. The windows 650 (and in some cases, the windows 645) shown in FIG. 6A may be inset into openings that extend through the back cover 607. Although the back cover 607 may include inset windows, the windows may form a smooth exterior surface with the back cover 607. As depicted in FIG. 6A, four of the eight windows (e.g., windows 650) may have an optically opaque or opaque material 687 around the perimeter of the window, which may determine the size of the aperture through which light may pass. The optically opaque or black material around the perimeter of the window may be an optical barrier for all light or an optical barrier for at least the range of wavelengths emitted and/or received by the emitters and the detectors of the wearable device. The other four windows (e.g., windows 645) may be integral portions of a monolithic back cover structure (i.e., the windows 645 may not be inset windows) and may be defined by an optical mask (e.g., an ink, film, coating, or surface treatment) on the back cover 607. For example, the ink film, coating, or surface treatment may be on first portions of the back cover 607 and absent on second portions of the back cover 607.

[0114] FIG. 6B illustrates an example of a back cover 607 of a wearable device from the side view. In some examples, the back cover 607 may be incorporated into some aspects of the wearable device 100 as described with reference to FIGS. 1A-6A. In the example of FIG. 6B, the back cover 607 may be incorporated in the wearable device to provide physiological and/or biometric measurements of the user wearing the wearable device as discussed with respect to FIGS. 1A-6A.

[0115] As illustrated in FIG. 6B, the side view may be a cross section of the back side of the wearable device as depicted in FIG. 6A. As depicted in FIG. 6A, the back cover 607 may include eight windows. As previously mentioned, any appropriate number of windows may be used and eight windows are used for explanatory and discussion purposes only. Each of windows 645 may provide an aperture through which an emitter may emit light and each of windows 650 may provide an aperture through which a detector may detect light reflected off of and/or backscattered from the user's tissue. By way of example, the cross section shown in FIG. 6B shows the windows 650 inset into, and extending through, the back cover 607. As previously discussed, the windows 645 may be integral portions of the back cover 607 and may not be inset. As shown in FIGS. 6A and 6B, there may be no window in the central portion (or center) of the wearable device. However, in some embodiments, there may be a central window as shown in FIG. 5A.

[0116] In FIG. 6B the back cover 607 may have an internal surface 604 which may be internal to the wearable device and an external surface 606 which may be external to the wearable device. The back cover 607 may include a substrate which may at least partially define the internal surface 604 and the external surface 606 of the wearable device. The external surface 606 may be the surface which may come into contact with the skin of the user wearing the wearable device. Similar to FIG. 5B, in FIG. 6B, the back cover 607 or skin-facing cover may have openings which may extend through the back cover. For example, the openings may extend through the internal surface 604 and the external surface 606 of the back cover 607. In this ledge-less example of FIG. 6B, glass or sapphire optically transparent frits 687 may include a central portion that is hollow (for example, similar to a hollow tube) and may be approximately cylindrical in shape. The frits 687 may be inserted into the openings of the back cover 607, and the frits may border the perimeter of the openings as illustrated in FIG. 6B and be melted or bonded to the back cover 607. Windows 650 may be disposed in the center of the frits 687 and the windows may be bonded in place and to the back cover 607. In some examples, windows 650 may provide an aperture through which light reflected off of and/or backscattered light passing through a user's arterial blood flow may be detected. By melting or bonding the frits and the windows 650 to the back cover, this may secure the frits and windows into place such that the windows may not be displaced or become tilted in the openings of the back cover 607. Additionally, the internal surface 604 and external surface 606 of the back cover 607 may be ground or polished to provide a back cover with smooth surfaces. Further, although the frits and windows may be depicted as round, the frits and the windows may be any appropriate shape. In some examples, the inner diameter of the frit may be any shape so long as the frit functions as an optical barrier and blocks the emitter to detector light path.

[0117] In some examples of FIG. 6B, the frits may be optically opaque. Either the frit material itself may be optically opaque, or the frits may be coated with an optically opaque material such as an optically opaque ink or a color neutral ink which may not distinguish between infrared and red light. The frits may be inserted into the opening, and the frits may have frit openings similar to a ring. Because the frits are similar to a ring with a hollow central opening, the inner diameter of the frit may provide an aperture through which light may still be detected. In some embodiments, the frit may be a glass frit (e.g., a black glass frit) which may be centered in the opening of the back cover 607. The black glass frit may form an optical bond with the sapphire opening after melting or bonding and then both sides of the back cover may be polished to achieve a smooth surface. In this embodiment, the masking of the emitter and/or detector may be determined by the shape of the ink and/or the frit. The frits may be any shape so long as the frit blocks the emitter to detector optical path.

[0118] In some examples, the back cover 607 may be an optically transparent material and the windows may also be optically transparent. The optically opaque frits may provide at least some optical isolation for the detectors so that stray emitter light may not be received at the detectors. Within a certain range of angles, light leaving the emitters may reflect off of the windows back toward the detector instead of passing through the window and into the tissue. Without

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optical isolation, this light that reflects off of the windows may be received by the detectors and may provide an erroneous measurement. With optical isolation, the light that reflects off of the windows and back towards the detector may be prevented from reaching the detector by the optically opaque frit that optically isolates the detector.

[0119] Similar to FIGS. 5A-5C, the size of the apertures through which light may pass to reach a detector may be at least partially determined by the inner diameter of the frit and/or the ink on the perimeter of the frit. In FIG. 6B, the inner diameter of the frit and/or the ink on the inner diameter of the frit may be the optical barrier between the emitters and the detectors. Accordingly, the area through which light may pass may be smaller than the openings in the back cover and instead may be the inner diameter of the frits.

[0120] FIG. 6C illustrates an example of a back cover 607 of a wearable device. In some examples, the back cover 607 may be incorporated into some aspects of the wearable device 100 as described with reference to FIGS. 1A-6B. In the example of FIG. 6C, the back cover 607 may be incorporated in the wearable device to provide physiological and/or biometric measurements of the user wearing the wearable device as discussed with respect to FIGS. 1A-6B.

[0121] As illustrated in FIG. 6C, the isometric view may be an example of the back cover 607 of the wearable device as depicted in FIGS. 6A and 6B. The back cover 607 may include four to eight windows. Windows 645 may provide an aperture through which an emitter may emit light, and in some cases may be integral with the back cover 607 and defined by the absence of an optical mask (e.g., an ink (an optically opaque ink), film, coating, or surface treatment) on other portions of the back cover 607. For example, the optical mask may be on first portions of the back cover 607, and absent from second portions of the back cover 607. Windows 650 may provide an aperture through which a detector may detect light reflected off of and/or backscattered from the user's tissue and may be inset into the back cover 607. In FIG. 6C, there may be no separately provided window in the central portion (or center) of the wearable device. However, the back cover 607, or a portion thereof, may in some cases be optically transparent to a range of electromagnetic radiation wavelengths that is emitted and/or received through the central portion of the back cover.

[0122] In FIG. 6C, the back cover 607 may include openings for the windows 650 that extend through the back cover. The openings may be ring shaped fits with an opening in the central portion and the frits may be inserted into the openings and may function as a sleeve that fits within the opening of the back cover. The inner diameter opening of the fits or the ink coated on the frits may determine the size of the aperture through which light may pass or be detected. Although the term frit may be used herein, a frit may be understood to be a hollow sleeve, ring, and/or tube shaped component or hollow cylindrical element regardless of material composition.

[0123] The windows 650 may be disposed in the frit center opening and may be optically transparent so that light may pass or be detected through the windows. The frits 687 may function as optical barriers between the emitters and detectors and may minimize or prevent internal crosstalk. Using optical isolation, any emitter light that reflects off of the windows and back towards the detector may be prevented from reaching the detector by the optically opaque frit that optically isolates the detector.

[0124] FIG. 7 illustrates an example 700 of a back cover, emitters, detectors, and waveguides of a wearable device from the side view. In some examples, the back cover 707 may be incorporated in the wearable device to provide physiological and/or biometric measurements of the user wearing the wearable device as discussed with respect to FIGS. 1A-6C.

[0125] As illustrated in FIG. 7, the side view may be a cross section of the wearable device as depicted in FIG. 5A. The back cover 707 may include six windows, but the side view of FIG. 7 shows an emitter window, and two detector windows. In FIG. 7, the emitter and detectors may be protected by a back or skin-facing cover with windows or apertures. Window 745 provides an aperture through which the emitter may emit light and window 750 may provide an aperture through which a detector may detect light reflected off of and/or backscattered from the user's tissue. As illustrated in FIG. 7, the window 745 for the emitter 705 and windows 750 for the near detector 730 and the far detector 735. The optional window 763 may be a window over the central portion of the back cover 707 of the wearable device. The windows may be disposed in openings 776 in the back cover 707 and the back cover 707 may be an optically transparent or opaque back cover. The openings in the back cover may extend through the interior surface and the exterior surface of the back cover. Alternatively, some or all of the windows may be integral with the back cover 707 and defined by an absence of an optical mask (e.g., an ink (an optically opaque ink), film, coating, or surface treatment) on other portions of the back cover 707. For example, the optical mask may be on first portions (non-window portions) of the back cover 707, and absent from second portions of the back cover 707. In some cases, and by way of example, the window 745 for the emitter 705 may be defined by the absence of an optical mask (e.g., the ink, film, coating, or surface treatment) that surrounds the window 745, and the windows 750 for the near detector 730 and the far detector 735 may be disposed in openings 776 in the back cover 707. The back cover 707 and/or windows 745, 750, 763 may be formed of sapphire, glass, plastic, or other materials.

[0126] In some cases, the emitter 705, the near detector 730, and the far detector 735 may be mounted to a PCB, and the PCB may be attached to the back cover 707 by one or more components that form a set of optical barriers (or walls) between the PCB and the back cover 707. In these cases, the back cover 707, in combination with the PCB and one or more components that form the set of optical barriers (or walls), may define different cavities in which the emitter 705, the near detector 730, and the far detector 735 are separately housed.

[0127] In FIG. 7, the optical path for emitted light, between the emitter 705 and the window 745, may be determined by an emitter waveguide 775. The emitter waveguide 775 may guide the emitted light from the emitter to the window. In some examples, the light may be received in a first end of the waveguide such that the light internally reflects off the walls of the waveguide. The light may exit a second end of the waveguide and through the window and/or into the tissue of the user wearing the device. The emitter waveguide 775 may be internally reflective at or around the wavelength of light being generated or emitted. Further, the emitter waveguide 775 may guide the emitted light via total internal reflection in the waveguide 775 and to the emitter window 745. Additionally, the emitter waveguide 775 may

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be configured to transmit the light from the emitter to the wrist of the user wearing the wearable device.

**[0128]** As depicted in FIG. 7, there may be an emitter waveguide 775 for each of the emitters which may emit different light wavelengths, but in some embodiments, there may be one waveguide configured to receive emitted light from more than one emitter. For example, the emitter waveguide 775 may be configured to receive all of the emitted green light, the emitted red light, and the emitted infrared light, and guide the light to the emitter window 745. In other examples, the emitter waveguide 775 may extend through the back cover of the wearable device and the back cover may not include windows. In this example, the emitters may emit the light through a housing of a reflective sensing device.

**[0129]** Also illustrated in FIG. 7, the optical path for light reflected off of and/or backscattered light that has passed through arterial or venous blood flow of the wrist, between the near detector 730 and the detector window 750, may be determined by the near waveguide 780. The near waveguide 780 may guide the reflected light from the window to the near detector 730. The near waveguide 780 may be internally reflective at or around the wavelength of light being received at the near detector 730. In some examples, the near detector 730 may be internally reflective at or around the range of red light, infrared light, and/or green light wavelengths. Further, the near waveguide 780 may guide the reflected light via total internal reflection in the waveguide 780, from the window and to the near detector 730. In some examples, the near waveguide 780 may extend through the back cover of the wearable device and the back cover may not include windows.

**[0130]** Similarly, the optical path between the far detector 735 and the detector window 750 may be determined by the far waveguide 785. The far waveguide 785 may guide the reflected light from the detector window 750 to the far detector 735. The far waveguide 785 may be internally reflective at or around the wavelength of light being received at the far detector 735. In some examples, the far detector 735 may be internally reflective at or around the range of red light, infrared light, and/or green light wavelengths. Further, the far waveguide 785 may guide the reflected light via total internal reflection in the far waveguide 785, from the window and to the far detector 735.

**[0131]** In some examples, the near and far detectors 730, 735 may include additional associated circuitry which may be configured to process the detected light measurements into signals and may provide these electrical signals to a processor. The processor may be configured to receive the signals from one or more of the detectors. Additionally, the processor may be further configured to determine a blood oxygenation level using at least a subset of the received signals and in some cases received detected light. In some examples, the processor may be configured to receive the signals representing a detected range of red light and infrared light wavelengths from a far detector 735 and a near detector 730. The processor may then determine a blood oxygenation level using a subset of the signals representing the received range of red light wavelengths and the received range of infrared light wavelengths.

**[0132]** The waveguides of FIG. 7 may be formed of sapphire, plastic, glass, or any other appropriate material. In some examples, the waveguides may be fiber optic waveguides which may be similar to a plastic rod with internally

reflective material that reflects light at or around a range of green light wavelengths, a range of red light wavelengths, and a range of infrared light wavelengths. In other examples, the waveguides may be similar to hollow tubes and internally reflective of light at or around a range of green light wavelengths, a range of red light wavelengths, and a range of infrared light wavelengths. The waveguides of FIG. 7 may be optically coupled with the emitters and detectors via butt coupling, one or more prisms, one or more lenses, and/or any other appropriate method, or any combination thereof. Additionally, the waveguides of FIG. 7, may be any appropriate shape such as a sheet or film, cable, straight, tapered, any combination thereof, and so forth. In some examples, the far waveguide 785 may extend through the back cover of the wearable device and the back cover may not include windows.

**[0133]** In other examples of FIG. 7, the back cover may have openings, but no optically transparent windows. Instead, the waveguide may fill the opening in the back cover. In this example, the waveguide may directly receive the reflected and/or backscattered light that has passed through the arterial and venous blood flow of the person. The waveguides may be plastic, glass, hardened glass, a solid rod, a hollow tube, or any other appropriate configuration or material or any combination thereof. In some examples, the waveguides may be fiber optic waveguides which may be similar to a solid plastic rod with internally solid reflective material that reflects light at or around green light wavelengths, red light wavelengths, and infrared light wavelengths. In other examples, the fiber optic waveguides may be similar to a hollow plastic tube in which the light may propagate through air, but the internal perimeter wall of the hollow plastic tube may be a reflective material that reflects ranges of light at or around green light wavelengths, red light wavelengths, and infrared light wavelengths.

**[0134]** The emitter waveguide 775, the near waveguide 780 and the far waveguide 785 may be optical waveguides, including but not limited to, fiber optic, single-mode, step index, gradient index, light guides, planar, films, any combination thereof, and so forth. In some examples, the emitter waveguide 775, the near waveguide 780 and the far waveguide 785 may be different types of waveguides from one another. The waveguides may be inserted into holes or openings machined into the back cover 707. The emitter waveguide 775 may ensure that the emitted light transmits toward the tissue and not directly toward the near detector 730 or the far detector 735. In some examples, each of the individual emitters of emitter 705 may have a corresponding waveguide. For example, the red light emitter may have a waveguide, the infrared light emitter may have a waveguide, and the green light emitter may have a waveguide. In additional examples, the near detector 730 and the far detector 735 may not have waveguides associated with the detectors as discussed with respect to FIGS. 5A-5D and 6A-6C.

**[0135]** In some examples, the emitter waveguide 775, the near waveguide 780 and the far waveguide 785 may have an internal core which is reflective of the wavelengths around green light, infrared light, and red light. Further, the core of the waveguide may be minimally absorbing around these wavelengths so that the greatest amount of the emitted light may be transmitted to the wrist tissue of the user wearing the wearable device and not absorbed by the waveguide. Additionally, the waveguide internal core may be minimally

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absorbing around these wavelengths so that the light reflected off of and/or backscattered from the wrist tissue may be detected by the near detector 730 and the far detector 735.

[0136] FIGS. 8A-8D illustrate various layouts 800, 805, 806, and 809 for the back cover of the wearable device. The windows of the back cover 807 shown in any of the layouts 800 described with reference to any of FIGS. 8A-8D may in some examples be configured so that a first set of windows may be configured to transmit emitted light to the wrist of the user and a second set of windows may be configured to detect light reflected off of the arterial flow of the user and/or backscattered light that has passed through arterial blood. Additionally, the layouts 800 may be used in any of the examples described with respect to FIGS. 1A-7. The back covers and/or windows in each of the layouts may be formed of sapphire, glass, plastic, or other materials.

[0137] FIG. 8A illustrates an example 800 of a back cover of a wearable device. In some examples, the back cover 807 may be incorporated in the wearable device to provide physiological and/or biometric measurements of the user wearing the wearable device as discussed with respect to FIGS. 1A-7. As illustrated in FIG. 8A, the back cover 807 may include six windows disposed around a central portion (or central window) as described herein. The windows of the back cover 807 in FIG. 8A may be circularly shaped and may provide nine optical paths between the emitters and detectors and may be used with either the ledge embodiments discussed with respect to FIGS. 5A-5D, the frit embodiments discussed with respect to FIGS. 6A-6C, or the waveguide embodiments discussed with respect to FIG. 7. In FIG. 8A, the emitting area may be defined by the inner diameter of the frit, or the distance between the inner edges of the ledges as discussed herein. Although the windows may be larger, the aperture through which light may pass may be determined by the optical barriers between the emitters and the detectors. In other examples of FIG. 8A, the windows of the back cover 807 in FIG. 8A may provide up to nine optical paths between the emitters and detectors.

[0138] FIG. 8B illustrates an example 803 of a back cover of a wearable device. In some examples, the back cover 807 may be incorporated in the wearable device to provide physiological and/or biometric measurements of the user wearing the wearable device as discussed with respect to FIGS. 1A-8A. As illustrated in FIG. 8B, the back cover 807 may include eight windows as described in detail herein. The windows of the back cover 807 in FIG. 8B may be rectangular and triangular shapes and may provide sixteen optical paths between the emitters and detectors, and in some examples, may provide up to sixteen optical paths between the emitters and detectors. The example of FIG. 8B may be used with either the ledge embodiments discussed with respect to FIGS. 5A-5D, the frit embodiments discussed with respect to FIGS. 6A-6C, or the waveguide embodiments discussed with respect to FIG. 7. In FIG. 8B, the shapes of the windows and apertures may be implemented to maximize the use of as much of the surface area of the back cover 807 as possible. Further, in FIG. 8B, the green light emitter may be located in the inner diameter of the triangular shapes and the red light emitter and the infrared light emitter may be located in the corners of the triangular shapes.

[0139] FIG. 8C illustrates an example 806 of a back cover of a wearable device. In some examples, the back cover 807

may be incorporated in the wearable device to provide physiological and/or biometric measurements of the user wearing the wearable device as discussed with respect to FIGS. 1A-8B. As illustrated in FIG. 8C, the back cover 807 may include eight windows as described in detail herein. The windows of the back cover 807 in FIG. 8C may be circular, and may provide sixteen optical paths between emitters and detectors. The example of FIG. 8C may be used with either the ledge embodiments discussed with respect to FIGS. 5A-5D, the frit embodiments discussed with respect to FIGS. 6A-6C, or the waveguide embodiments discussed with respect to FIG. 7.

[0140] In FIG. 8C, the windows 850 through which light may be detected after reflecting off of the wrist arterial flow may include optical barriers (e.g., ledges, inks, films, coatings, surface treatments, or frits, as described with reference to FIGS. 1B-7) that extend through the back cover 807, around (or defining) the inner diameters of the windows. Although all of the apertures may be the same size in FIG. 8C, the windows 845 through which emitted light may pass may not have optical barriers that extend through the back cover 807 (but may). Instead, the windows 845 may be integral with the back cover 807 (i.e., the windows 845 may not be inset windows) and have diameters defined by an absence of an optical mask (e.g., an ink (an optically opaque ink), film, coating, or surface treatment) applied to other portions of the inner or outer surface of the back cover 807. For example, the optical mask may be on first portions (e.g., non-window portions) of the back cover 807, and absent from second portions of the back cover 807. The optical mask may define a size of an aperture over each emitter, but may not block light from being redirected within the back cover 807. However, emitted light that is redirected within the back cover 807, without exiting the back cover 807, may be blocked from reaching a detector by the optical barriers that extend through the back cover 807 and around detector windows. The optical barriers may be formed by one or more of an ink, film, coating, surface treatment, or frit disposed between a window and its respective opening, which in some cases may be entirely or partially surrounded by a stepped or tapered ledge. In the cases of an ink, film, coating, or surface treatment, the ink, film, coating, or surface treatment may be formed on, or applied to, the window or the opening (or ledge) before the window is abutted to and attached to the opening (or ledge). The windows 850 may be larger than the windows 845, but the apertures of windows 850 and the apertures of the windows 850 may be the same size. In some examples, the windows 850 may include an optical barrier, for example the ledges or the frits, which may result in the apertures being smaller than the windows 850.

[0141] FIG. 8D illustrates an example 809 of a back cover of a wearable device. In some examples, the back cover 807 may be incorporated in the wearable device to provide physiological and/or biometric measurements of the user wearing the wearable device as discussed with respect to FIGS. 1A-8C. As illustrated in FIG. 8D, the back cover 807 may include eight windows as described in detail herein. The windows of the back cover 807 in FIG. 8D may be rectangular and circular shapes and may provide sixteen optical paths between the emitters and detectors. The example of FIG. 8D may be used with either the ledge embodiments discussed with respect to FIGS. 5A-5D, the frit embodiments discussed with respect to FIGS. 6A-6C, or



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the waveguide embodiments discussed with respect to FIG. 7. In FIG. 8D, the shapes of the windows and apertures may be implemented to maximize the use of as much of the surface area of the back cover **807** as possible. Further, in FIG. 8D, the emitters may be linear shaped to use as much of the aperture opening as possible. With the implementation of the linear shaped emitters, the emitters may emit stronger or more intense light for transmission into the wrist tissue of the user. In other examples, the windows of the back cover **807** in FIG. 8D may provide up to sixteen optical paths between the emitters and detectors.

[0142] FIGS. 9A and 9B illustrate various layouts for the back cover of the wearable device. The windows of the back cover shown in the layouts **900** and **913** described with reference to both FIGS. 9 and 10 may in some examples be configured so that windows may be configured to transmit emitted light to the wrist of the user and may be further configured to detect light reflected off of the arterial flow of the user and/or backscattered light that has passed through arterial blood. Additionally, the layouts may be used in any of the examples described with respect to FIGS. 1A-8D.

[0143] FIG. 9A illustrates a layout **900** of a back cover of a wearable device. In some examples, the back cover **907** may be incorporated in the wearable device to provide physiological and/or biometric measurements of the user wearing the wearable device as discussed with respect to FIGS. 1A-8D. As illustrated in FIG. 9A, the back cover **907** may include six windows disposed around a central portion (or central window) of the back cover **907**, similar to FIG. 8A, and may provide nine optical paths between the emitters and detectors. In other examples of FIG. 9A, the back cover **907** may include six windows similar to FIG. 8A and may provide up to nine optical paths between the emitters and detectors. The windows of the back cover **907** in FIG. 9A may be circular shapes. The windows may alternatively have alternate shapes or sizes, and may be more or fewer in number.

[0144] As illustrated in FIG. 9A, the green light emitter **905a** of emitter **905** may emit green light. The green light may be transmitted from the green light emitter and may reflect off of the arterial blood flow, and may be detected by detectors **925** and **930**. FIG. 9A depicts that the light reflected off of the blood vessels may be stronger or a higher intensity in some locations and weaker or a lower intensity in other locations. Due to the circular layout and circular shape of the windows and apertures, only part of the reflected green light may line up with the detectors. Although the signal may provide useful information, it may be desirable for as much reflected light as possible to be detected by the detector, as opposed to only part of the reflected light being detected on the periphery of the detector.

[0145] FIG. 9B illustrates a layout **913** of a back cover of a wearable device. In some examples, the back cover **907** may be incorporated in the wearable device to provide physiological and/or biometric measurements of the user wearing the wearable device as discussed with respect to FIGS. 1A-8D. As illustrated in FIG. 9B, the back cover **907** may include eight windows similar to the layout of FIG. 8B and may provide sixteen optical paths between the emitters and detectors. In other examples of FIG. 9B, the back cover **907** may include eight windows and may provide up to

sixteen optical paths between the emitters and detectors. The windows of the back cover **907** in FIG. 9B may be triangular and rectangular shapes.

[0146] As illustrated in FIG. 9B, the green light emitter **905a** of emitter **905** may emit green light and as previously discussed may be located in the inner part of the triangular window and aperture. The green light may be transmitted from the green light emitter and may reflect off of the arterial blood flow, and may be detected by detectors **925** and **930**. FIG. 9B depicts that the light reflected off of the blood vessels may be stronger or a higher intensity in some locations and weaker or a lower intensity in other locations. Due to the circular layout and the rectangular shape of the windows and apertures for the detectors **925** and **930**, the reflected green light may “line up” or overlap with most to all of the detecting area of the detectors **925** and **930**. The detectors **925** and **930** may receive or detect as much reflected light as possible, as opposed to detecting reflected light in the periphery of the detector as described with respect to FIG. 9A.

[0147] The described layouts and configurations of the wearable device in FIG. 1A-9B have been for explanatory purposes. In alternative embodiments, the described embodiments may include a different combination or configuration of components, or may perform additional or alternative functions. The layouts and configurations described herein may be used as part of an electronic device, such as, in a watch, a biometric sensor, or in any other appropriate device.

[0148] In various embodiments, components or inks are indicated to be “opaque” or “optically opaque.” A component or ink is typically optically opaque to an emitted or received electromagnetic radiation wavelength of a component over which it is positioned, or to a range of emitted or received electromagnetic radiation wavelengths, and may thus block the wavelength(s). In some cases, the components or inks may also be optically opaque to, or block, other or all electromagnetic radiation wavelengths. In some cases, a component or ink may also be optically opaque to visible light for aesthetic reasons and/or other reasons.

[0149] In various embodiments, components or inks are indicated to be “transparent” or “optically transparent.” A component or ink may only be optically transparent to an emitted or received electromagnetic radiation wavelength of a component over which it is positioned, or to a range of emitted or received electromagnetic radiation wavelengths, and may thus pass the wavelength(s). In some cases, the components or inks may also be optically transparent to, or pass, other or all electromagnetic radiation wavelengths.

[0150] In some embodiments, the inks described herein may alternatively be or include one or more of a coating, surface treatment, and so on. In some embodiments, multiple inks, coatings, or surface treatments may be combined to provide one or more bands of optical blocking and/or optical transparency.

[0151] In some embodiments, opaque, selectively opaque, and/or selectively transparent components, inks, coatings, surface treatments, or the like may be used to reduce unwanted optical crosstalk between an emitter and a receiver, or between different optical paths.

[0152] FIG. 10 illustrates a sample electrical block diagram of an electronic device **1000**, and which may be the electronic device described with reference to FIGS. 1A-9B. The electronic device **1000** may include a display **1002** (e.g.,

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a light-emitting display on the front side of a wearable device), a processor **1004**, a power source **1006**, a memory **1008** or storage device, a sensor system **1010**, and an input/output (I/O) mechanism **1012** (e.g., an input/output device and/or input/output port). The processor **1004** may control some or all of the operations of the electronic device **1000**. The processor **1004** may communicate, either directly or indirectly, with substantially all of the components of the electronic device **1000**. For example, a system bus or other communication mechanism **1014** may provide communication between the processor **1004**, the power source **1006**, the memory **1008**, the sensor system **1010**, and/or the I/O mechanism **1012**.

[0153] The processor **1004** may be implemented as any electronic device capable of processing, receiving, or transmitting data or instructions. For example, the processor **1004** may be a microprocessor, a central processing unit (CPU), an application-specific integrated circuit (ASIC), a digital signal processor (DSP), or combinations of such devices. As described herein, the term “processor” is meant to encompass a single processor or processing unit, multiple processors, multiple processing units, or other suitably configured computing element or elements.

[0154] It should be noted that the components of the electronic device **1000** may be controlled by multiple processors. For example, select components of the electronic device **1000** may be controlled by a first processor and other components of the electronic device **1000** may be controlled by a second processor, where the first and second processors may or may not be in communication with each other. In some embodiments, the processor **1004** may include any of the processors and/or may be capable of any of the processing steps described herein.

[0155] The power source **1006** may be implemented with any device capable of providing energy to the electronic device **1000**. For example, the power source **1006** may be one or more batteries or rechargeable batteries. Additionally or alternatively, the power source **1006** may be a power connector or power cord that connects the electronic device **1000** to another power source, such as a wall outlet.

[0156] The memory **1008** may store electronic data that may be used by the electronic device **1000**. For example, the memory **1008** may store electrical data or content such as, for example, audio and video files, documents and applications, device settings and user preferences, timing signals, control signals, data structures or databases, image data, biometric data, or focus settings. The memory **1008** may be configured as any type of memory. By way of example only, the memory **1008** may be implemented as random access memory, read-only memory, Flash memory, removable memory, other types of storage elements, or combinations of such devices.

[0157] The electronic device **1000** may also include a sensor system **1010**, which in turn includes one or more sensors positioned substantially anywhere on the electronic device **1000**, for example the back side of a wearable device. The sensor(s) may be configured to sense substantially any type of characteristic, such as but not limited to, pressure, electromagnetic radiation (light), touch, heat, movement, relative motion, biometric data, and so on. For example, the sensor(s) may include a heat sensor, a position sensor, a light or optical sensor, an accelerometer, a pressure transducer, a gyroscope, a magnetometer, a health monitoring sensor, and so on. Additionally, the one or more sensors may utilize any

suitable sensing technology, including, but not limited to, capacitive, ultrasonic, resistive, optical, ultrasound, piezo-electric, and thermal sensing technology.

[0158] The I/O mechanism **1012** may transmit and/or receive data from a user or another electronic device. An I/O device may include a display, a touch sensing input surface such as a track pad, one or more buttons (e.g., a graphical user interface “home” button), one or more cameras, one or more emitters and/or detectors (e.g., the wearable device with biometric sensors described with reference to FIGS. 1A-9B as described herein), one or more microphones or speakers, one or more ports such as a microphone port, and/or a keyboard. Additionally or alternatively, an I/O device or port may transmit electronic signals via a communications network, such as a wireless and/or wired network connection. Examples of wireless and wired network connections include, but are not limited to, cellular, Wi-Fi, Bluetooth, IR, and Ethernet connections.

[0159] The foregoing description, for purposes of explanation, uses specific nomenclature to provide a thorough understanding of the described embodiments. However, it will be apparent to one skilled in the art, after reading this description, that the specific details are not required in order to practice the described embodiments. Thus, the foregoing descriptions of the specific embodiments described herein are presented for purposes of illustration and description. They are not targeted to be exhaustive or to limit the embodiments to the precise forms disclosed. It will be apparent to one of ordinary skill in the art, after reading this description, that many modifications and variations are possible in view of the above teachings, and that various features of the example embodiments may be combined for a particular application.

[0160] The present disclosure recognizes that personal information data, including the biometric data acquired using the presently described technology, can be used to the benefit of users. For example, the use of biometric authentication data can be used for convenient access to device features without the use of passwords. In other examples, user biometric data is collected for providing users with feedback about their health or fitness levels. Further, other uses for personal information data, including biometric data that benefit the user are also contemplated by the present disclosure.

[0161] The present disclosure further contemplates that the entities responsible for the collection, analysis, disclosure, transfer, storage, or other use of such personal information data will comply with well-established privacy policies and/or privacy practices. In particular, such entities should implement and consistently use privacy policies and practices that are generally recognized as meeting or exceeding industry or governmental requirements for maintaining personal information data private and secure, including the use of data encryption and security methods that meets or exceeds industry or government standards. For example, personal information from users should be collected for legitimate and reasonable uses of the entity and not shared or sold outside of those legitimate uses. Further, such collection should occur only after receiving the informed consent of the users. Additionally, such entities would take any needed steps for safeguarding and securing access to such personal information data and ensuring that others with access to the personal information data adhere to their privacy policies and procedures. Further, such entities can

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subject themselves to evaluation by third parties to certify their adherence to widely accepted privacy policies and practices.

[0162] Despite the foregoing, the present disclosure also contemplates embodiments in which users selectively block the use of, or access to, personal information data, including biometric data. That is, the present disclosure contemplates that hardware and/or software elements can be provided to prevent or block access to such personal information data. For example, in the case of biometric authentication methods, the present technology can be configured to allow users to optionally bypass biometric authentication steps by providing secure information such as passwords, personal identification numbers (PINS), touch gestures, or other authentication methods, alone or in combination, known to those of skill in the art. In another example, users can select to remove, disable, or restrict access to certain health-related applications collecting users' personal health or fitness data.

What is claimed is:

1. A wearable device, comprising:
  - a housing having a back cover;
  - an optical mask on first portions of the back cover;
  - the back cover including a set of windows, wherein,
    - a first subset of windows in the set of windows is defined by an absence of the optical mask on second portions of the back cover; and
    - a second subset of windows in the set of windows is inset in a set of openings in the back cover;
  - an optical barrier surrounding each window in the second subset of windows;
  - a set of light emitters configured to emit light through at least some of the windows in the set of windows; and
  - a set of light detectors configured to receive light through at least some of the windows in the set of windows.
2. The wearable device of claim 1, wherein:
  - the set of light emitters is configured to emit light through the first subset of windows; and
  - the set of light detectors is configured to receive light through the second subset of windows.
3. The wearable device of claim 1, wherein the set of light emitters comprises:
  - a set of red light emitters; and
  - a set of infrared light emitters.
4. The wearable device of claim 3, further comprising:
  - a processor configured to determine a blood oxygenation level using outputs of the set of light detectors indicating,
    - returned amounts of red light emitted by the set of red light emitters; and
    - returned amounts of infrared light emitted by the set of infrared light emitters.
5. The wearable device of claim 3, wherein the set of light emitters further comprises a set of green light emitters.
6. The wearable device of claim 3, wherein, for each window in the first subset of windows, a red light emitter in the set of red light emitters and an infrared light emitter in the set of infrared light emitters is configured to emit light through a respective window in the first subset of windows.
7. The wearable device of claim 1, wherein the optical barrier surrounding each window in the second subset of windows comprises at least one of an ink, film, coating, or surface treatment disposed between a window in the second subset of windows and a respective opening in the back cover.

8. The wearable device of claim 7, wherein:

the back cover includes a stepped ledge extending partly or wholly around each opening in the back cover; and each window in the second subset of windows abuts the stepped ledge that extends partly or wholly around a respective opening in the back cover.

9. The wearable device of claim 7, wherein:

the back cover includes a tapered ledge extending partly or wholly around each opening in the back cover; and each window in the second subset of windows abuts the tapered ledge that extends partly or wholly around a respective opening in the back cover.

10. The wearable device of claim 1, wherein the optical barrier surrounding each window in the second subset of windows comprises a glass frit.

11. The wearable device of claim 1, wherein:

the back cover is formed of sapphire; and each window in the second subset of windows is formed of sapphire.

12. The wearable device of claim 1, wherein each of the first subset of windows and the second subset of windows is disposed around a central portion of the back cover.

13. A wearable device, comprising:

a first set of emitters configured to emit a range of red light wavelengths;

a second set of emitters configured to emit a range of infrared light wavelengths;

a set of detectors, each detector in the set of detectors configured to detect amounts of at least the range of red light wavelengths and the range of infrared light wavelengths; and

a processor configured to,

operate the first set of emitters and the second set of emitters;

receive indicators of the amounts of at least the range of red light wavelengths and the range of infrared light wavelengths detected by the set of detectors; and

determine a blood oxygenation level using at least a subset of the indicators.

14. The wearable device of claim 13, wherein:

for each emitter in the first set of emitters and each emitter in the second set of emitters, the set of detectors comprises at least,

a first detector that detects emitted light on a first optical path having a first length; and

a second detector that detects emitted light on a second optical path having a second length different from the first length.

15. The wearable device of claim 13, further comprising: a third set of emitters configured to emit a range of green light wavelengths; wherein,

each detector in the set of detectors is further configured to detect the emitted range of green light wavelengths; and

the processor is further configured to,

operate the third set of emitters; and

receive indicators of amounts of the detected range of green light wavelengths received by the set of detectors.

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**16.** The wearable device of claim **15**, wherein:  
the processor is further configured to,  
use the indicators of the amounts of the detected range  
of green light wavelengths to determine the at least  
subset of the indicators used to determine the blood  
oxygenation level.

**17.** A wearable device, comprising:  
a housing;  
a display viewable through a front side of the housing;  
a skin-facing cover on a back side of the housing and  
having:  
an interior surface;  
an exterior surface; and  
a set of ledges bordering a set of openings, the set of  
openings extending through the skin-facing cover  
from the interior surface to the exterior surface;  
a set of windows disposed in the set of openings and  
abutting the set of ledges; and  
a set of photodetectors disposed within the housing and  
configured to receive light through the set of windows.

**18.** The wearable device of claim **17**, wherein:  
the skin-facing cover is formed of sapphire; and  
each window in the set of windows is formed of sapphire.

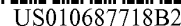
**19.** The wearable device of claim **17**, wherein:  
the set of ledges are stepped ledges;  
an ink that is opaque to at least a range of red light  
wavelengths and a range of infrared light wavelengths  
detectable by the set of photodetectors.

**20.** The wearable device of claim **19**, further comprising:  
a set of red light emitters;  
a set of infrared light emitters; and  
a set of green light emitters; wherein,  
the set of windows is a first set of windows;  
the skin-facing cover further includes a second set of  
windows;

a red light emitter in the set of red light emitters, an  
infrared light emitter in the set of infrared light emit-  
ters, and a green light emitter in the set of green light  
emitters is disposed under each window in the second  
set of windows; and

windows in the first set of windows and the second set of  
windows are interspersed in a ring around a central  
portion of the skin-facing cover.

\* \* \* \* \*



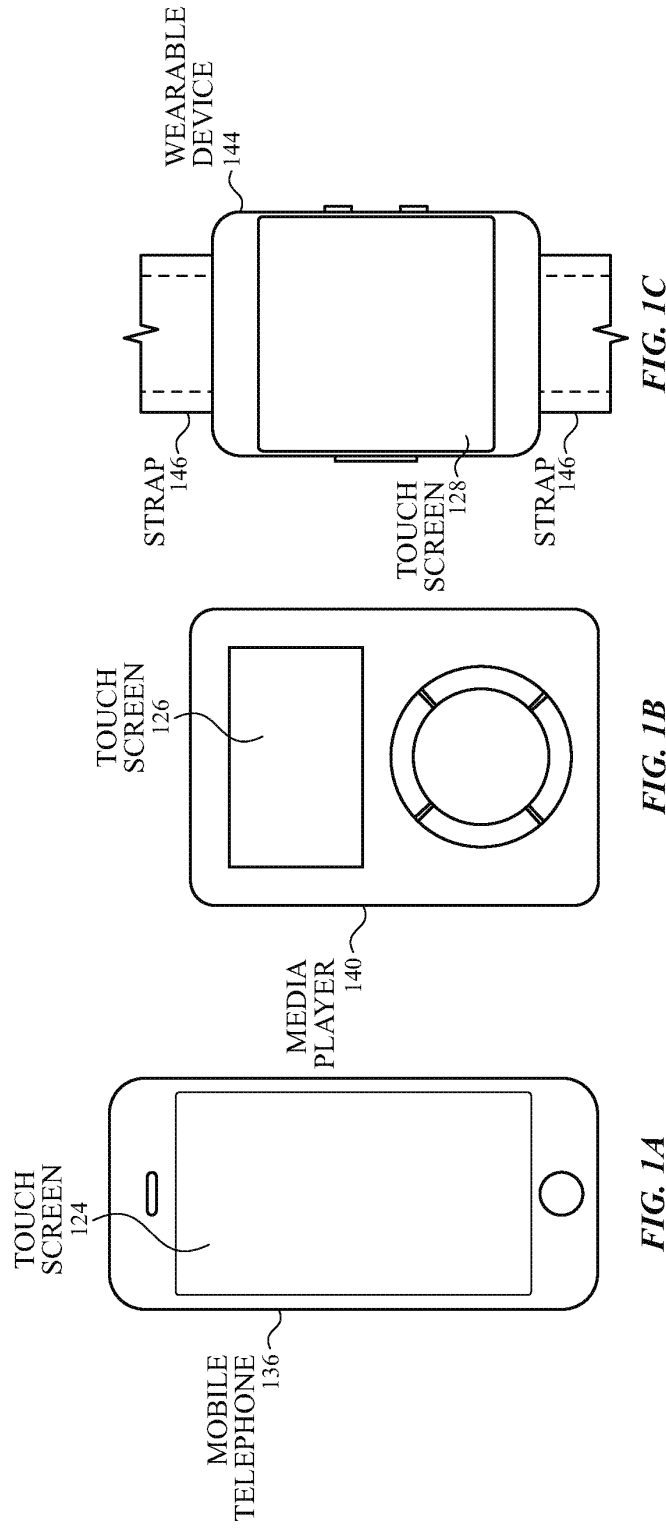
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- (52) **U.S. Cl.**
- CPC ..... *A61B 5/02427* (2013.01); *A61B 5/02438* (2013.01); *A61B 5/11* (2013.01); *A61B 5/14552* (2013.01); *A61B 5/681* (2013.01); *A61B 5/6843* (2013.01); *A61B 5/6898* (2013.01); *A61B 5/721* (2013.01); *A61B 5/7214* (2013.01); *A61B 5/7264* (2013.01); *A61B 5/02433* (2013.01); *A61B 2562/0219* (2013.01); *A61B 2562/0238* (2013.01); *A61B 2562/046* (2013.01); *A61B 2562/146* (2013.01); *A61B 2562/185* (2013.01)
- (58) **Field of Classification Search**
- CPC ..... A61B 5/6843; A61B 5/681; A61B 5/11; A61B 5/0295; A61B 5/0261; A61B 5/7214; A61B 5/02427; A61B 5/02438; A61B 2562/046; A61B 2562/0238; A61B 2562/0219; A61B 5/02433; A61B 2562/146; A61B 2562/185
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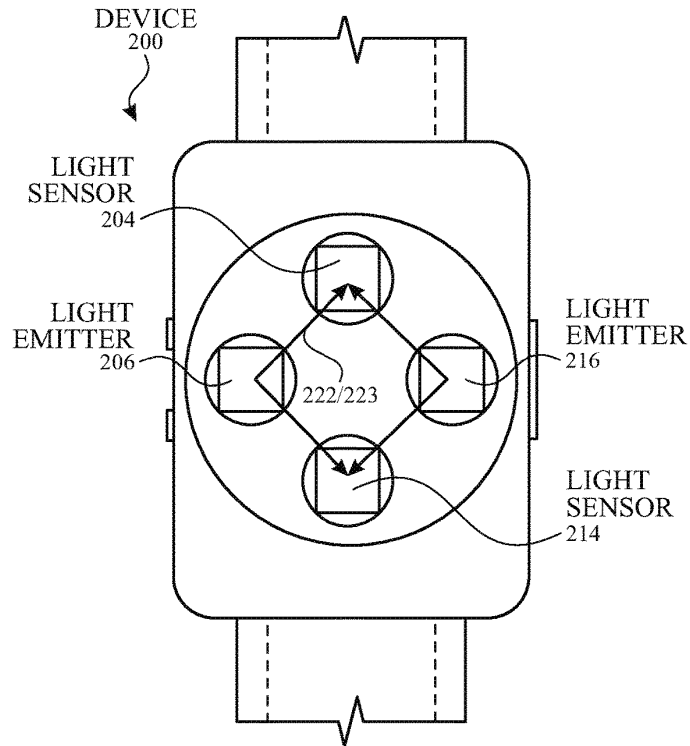


FIG. 2A

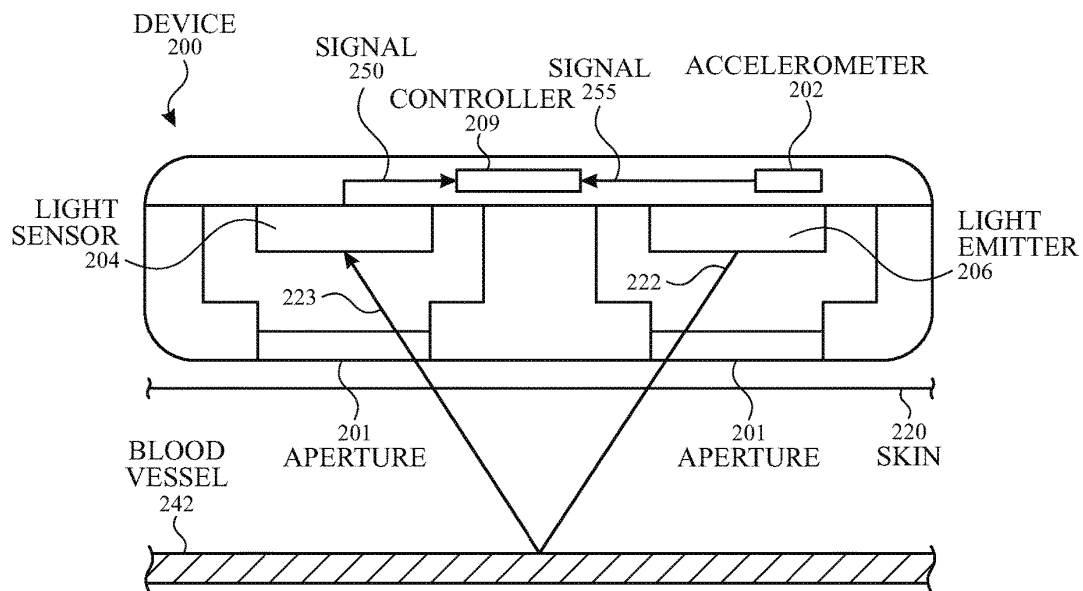


FIG. 2B



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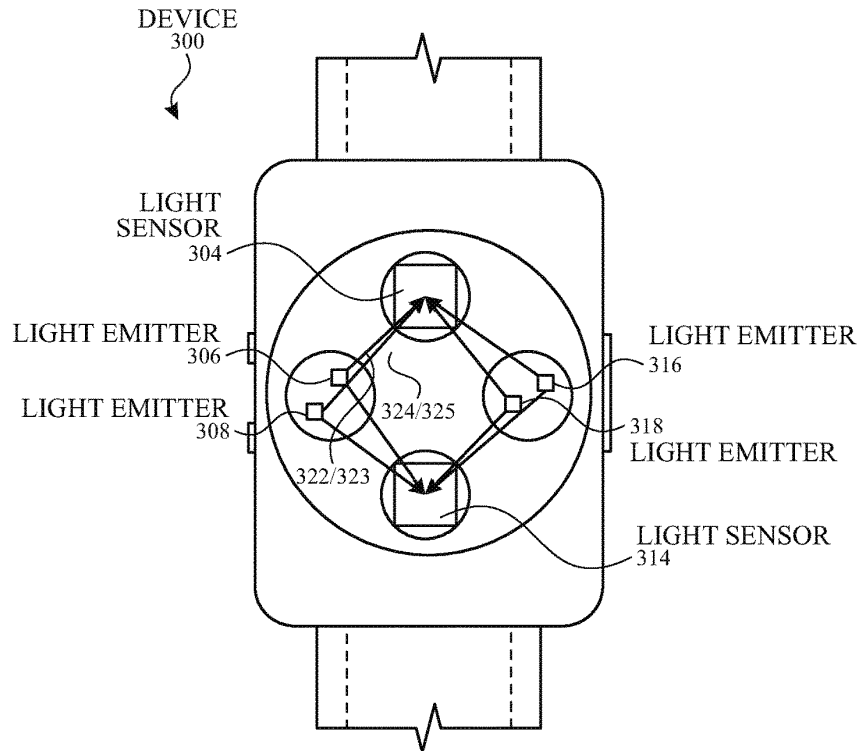


FIG. 3A

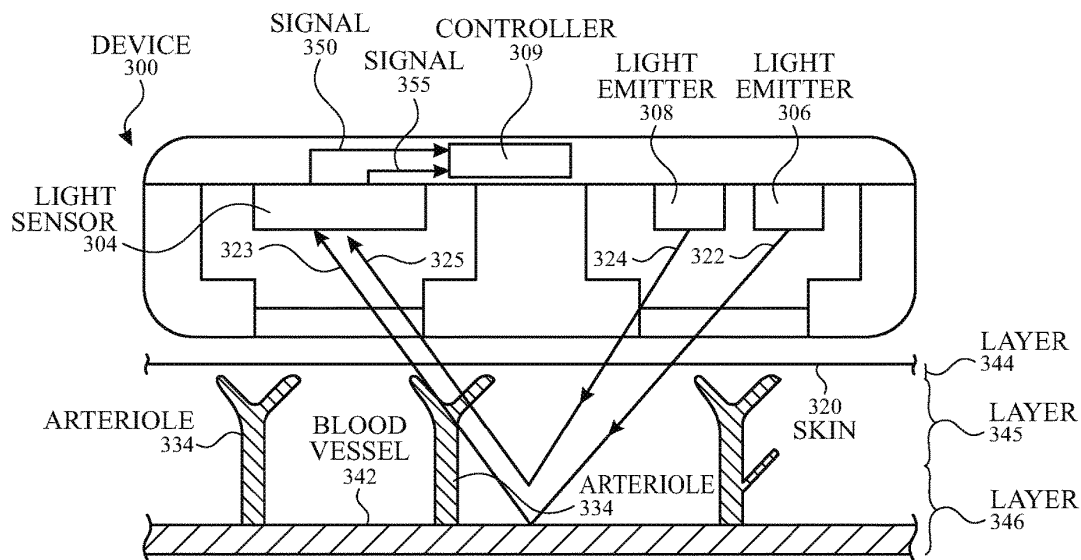


FIG. 3B

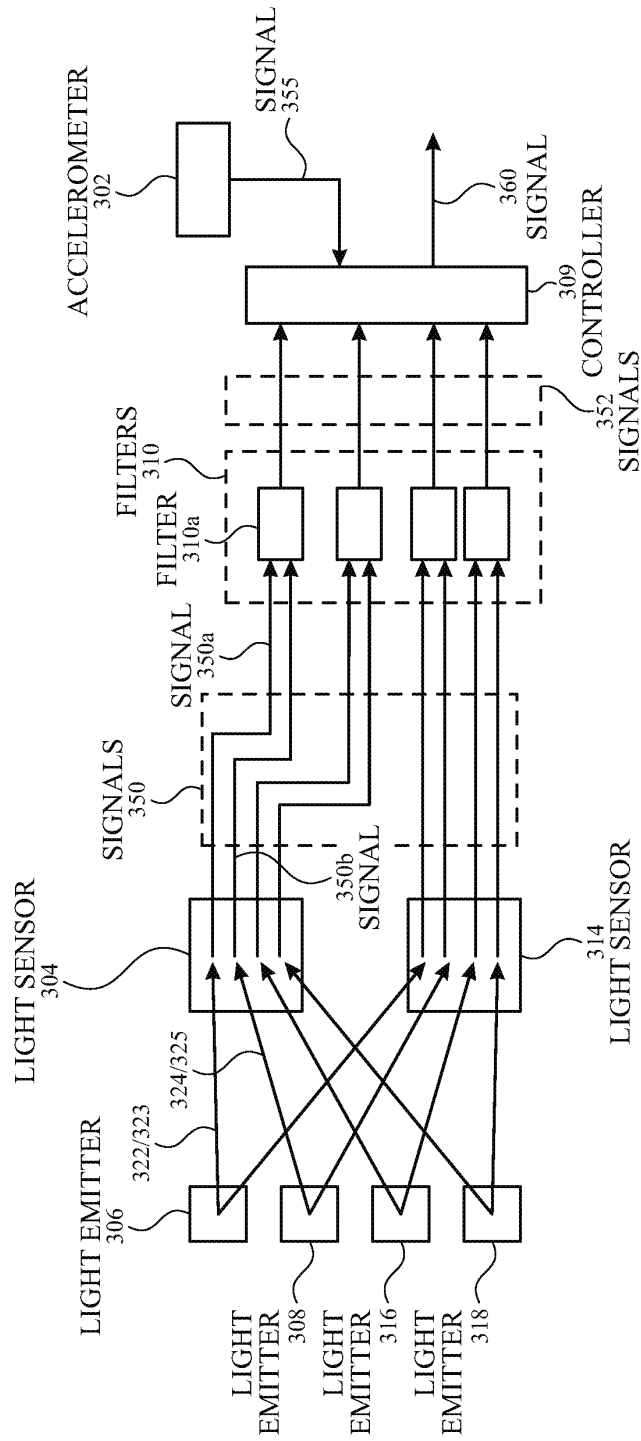


FIG. 3C

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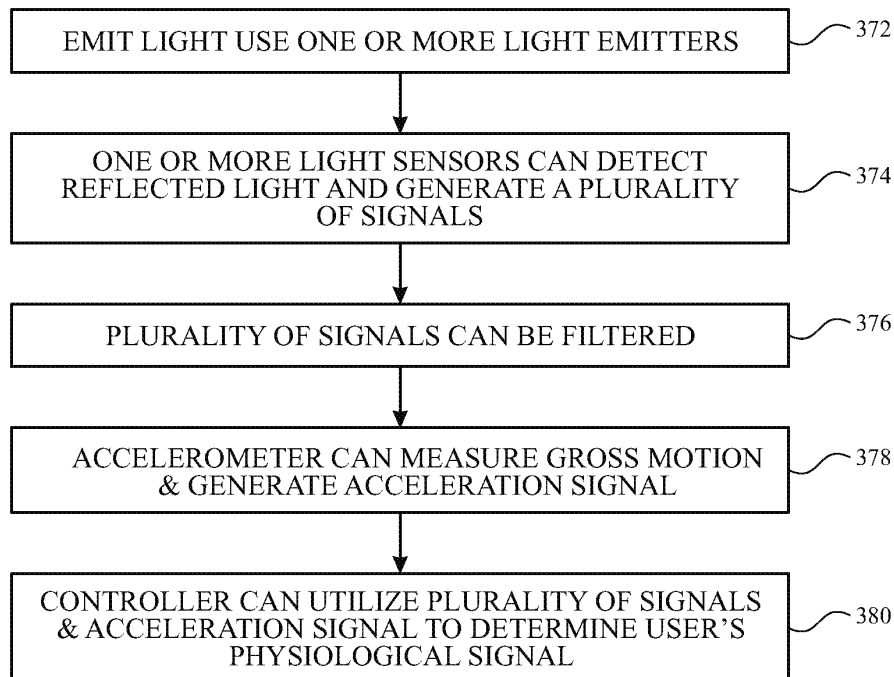
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**FIG. 3D**

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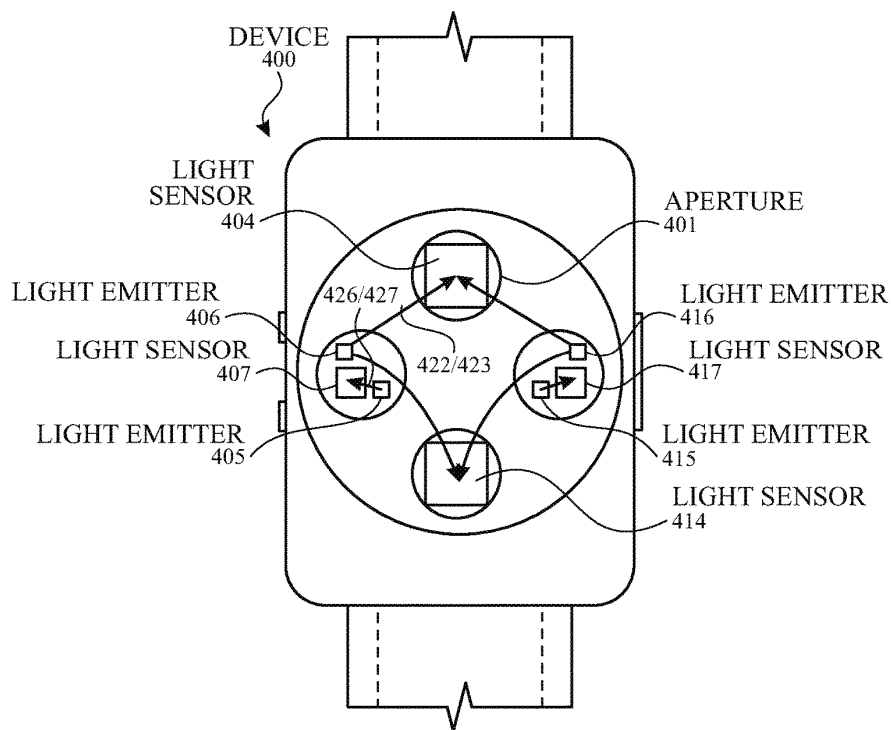


FIG. 4A

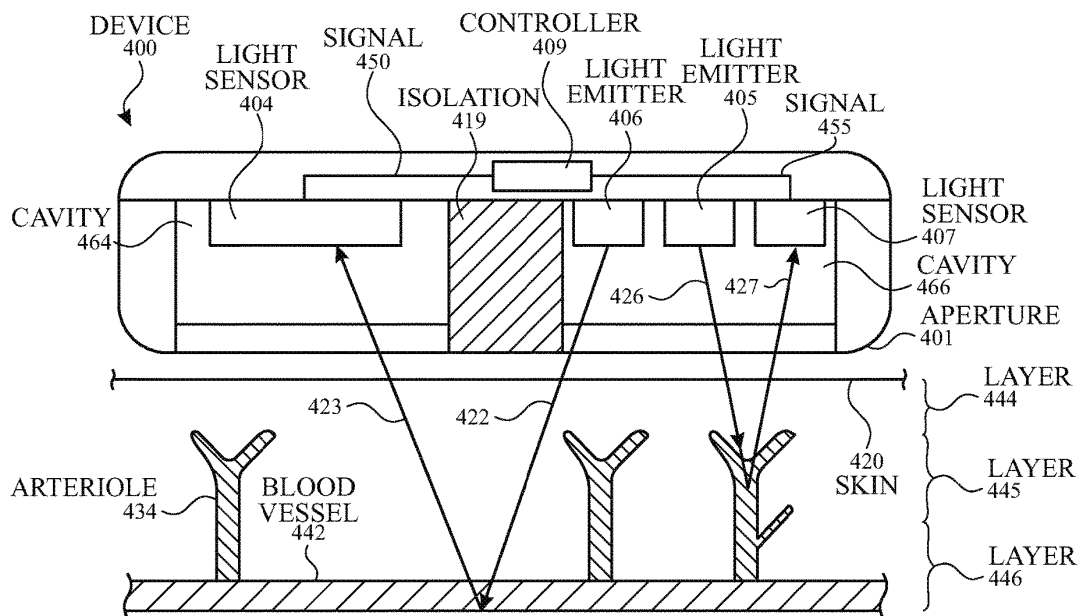


FIG. 4B

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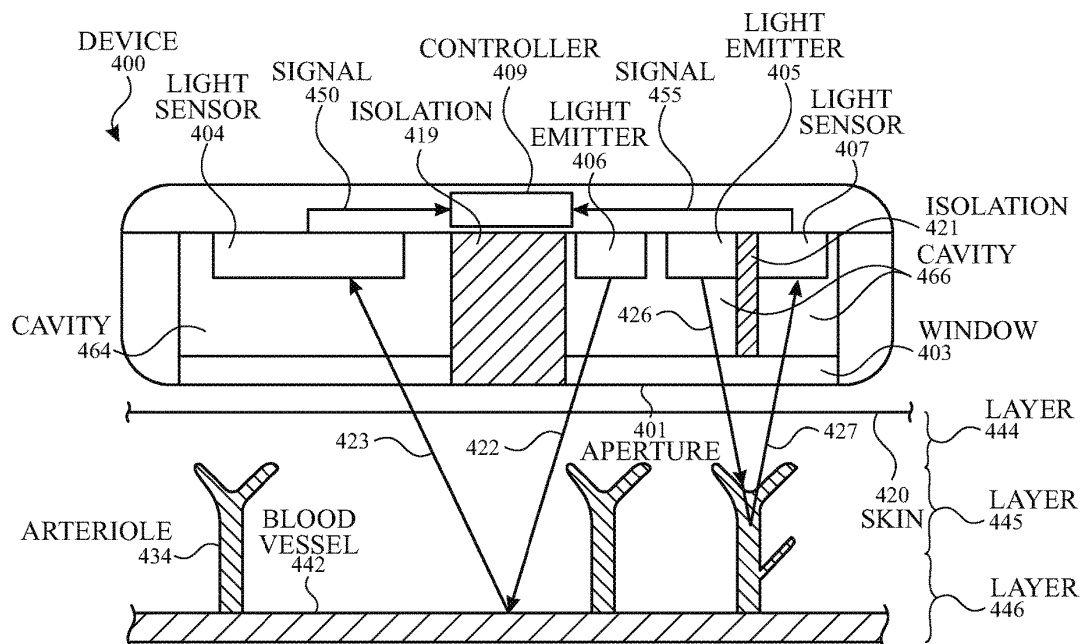


FIG. 4C

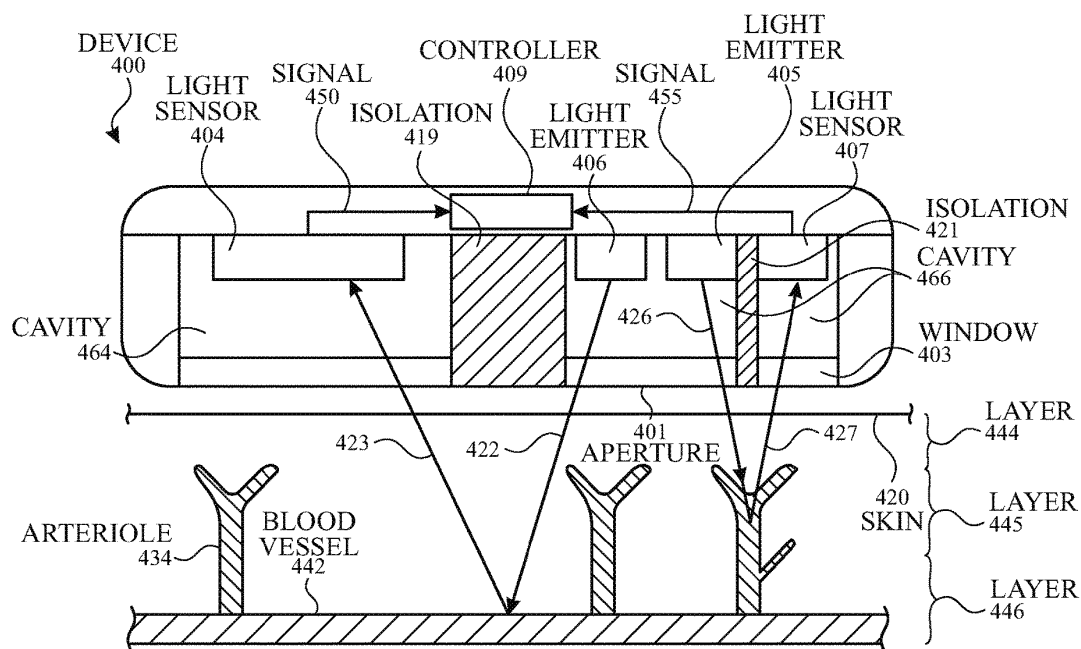


FIG. 4D

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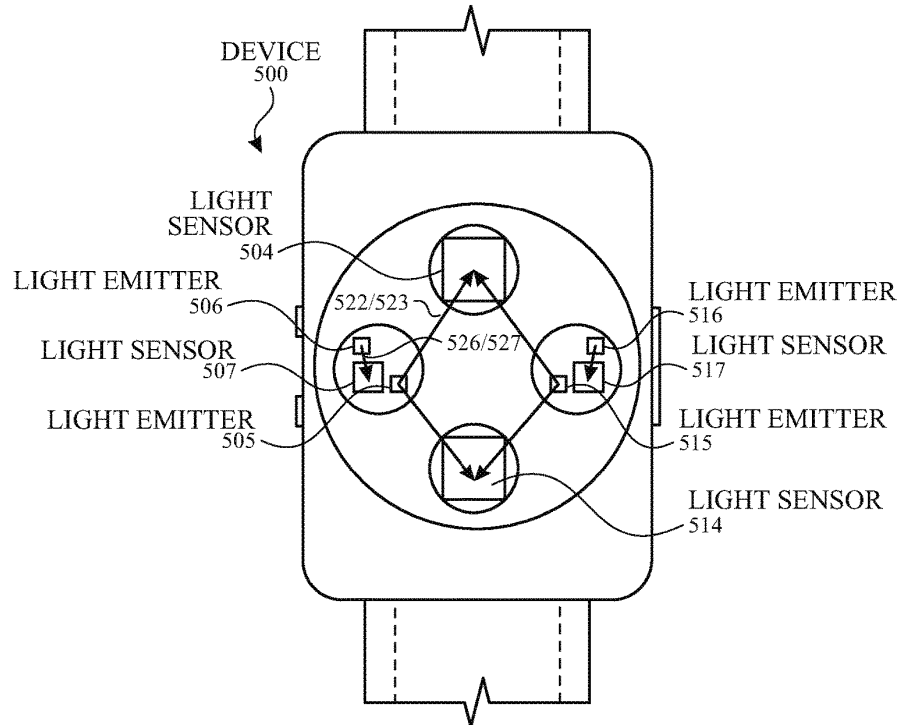


FIG. 5A

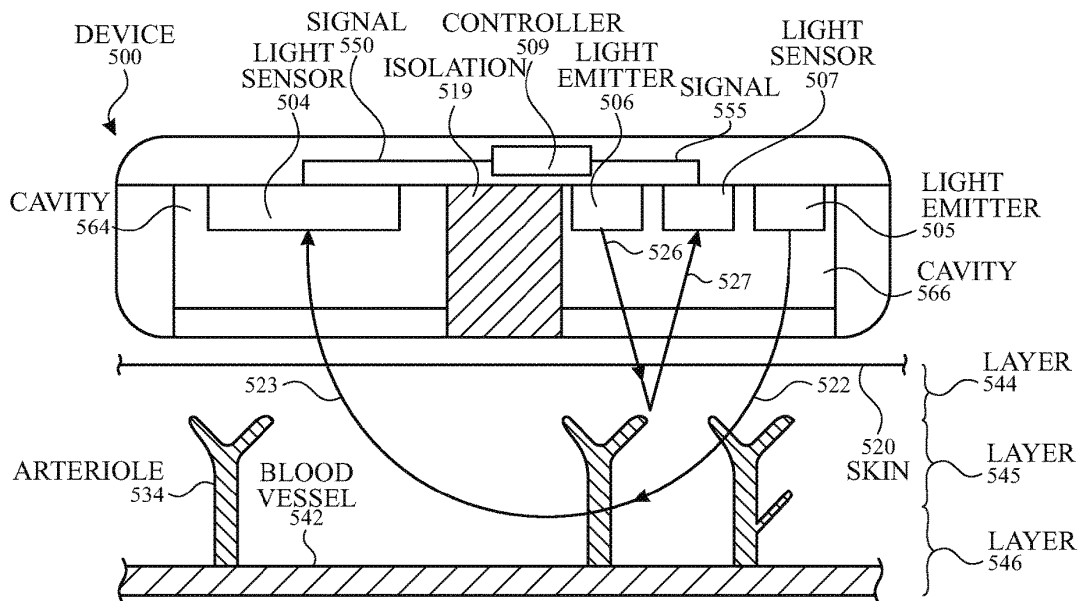


FIG. 5B

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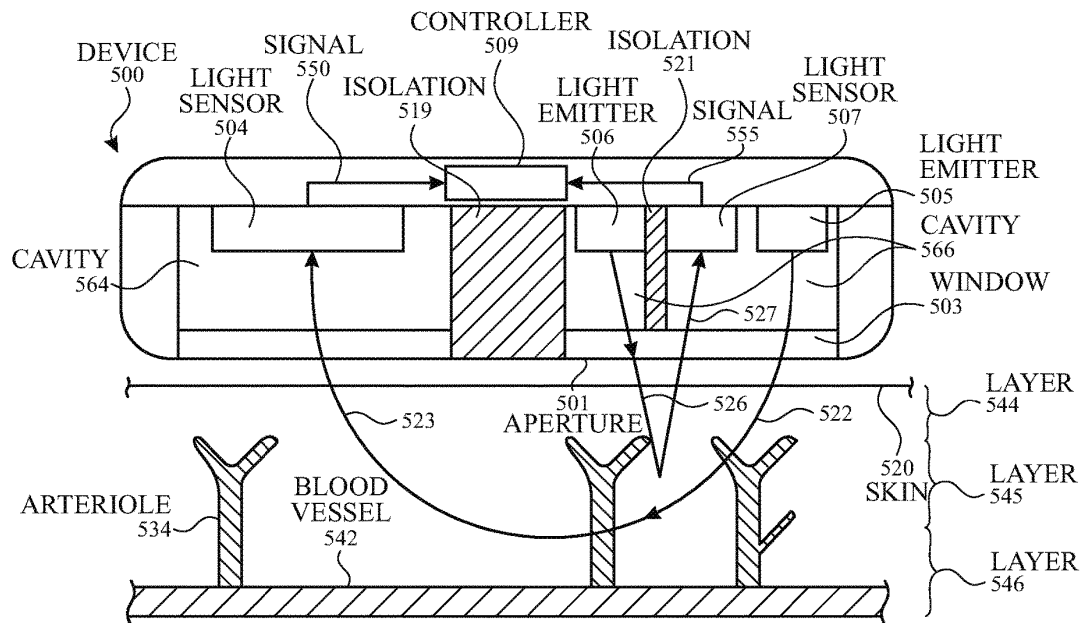


FIG. 5C

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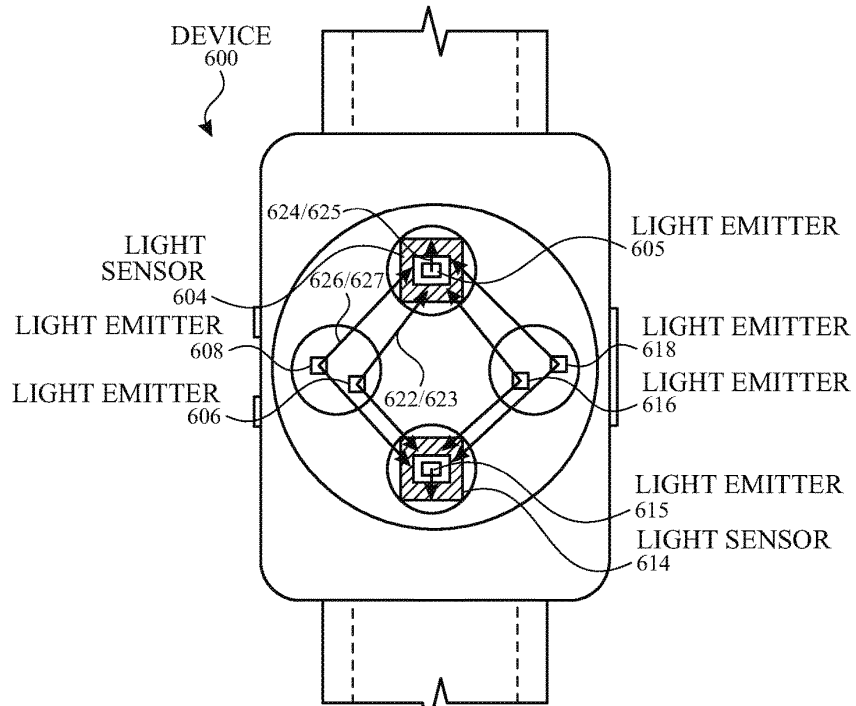


FIG. 6A

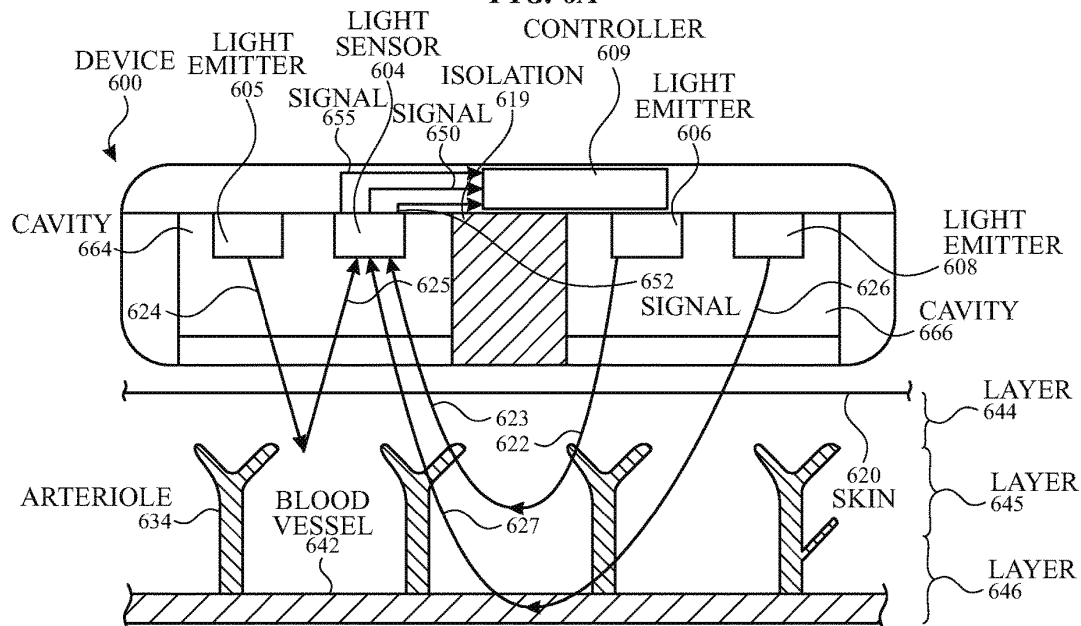


FIG. 6B



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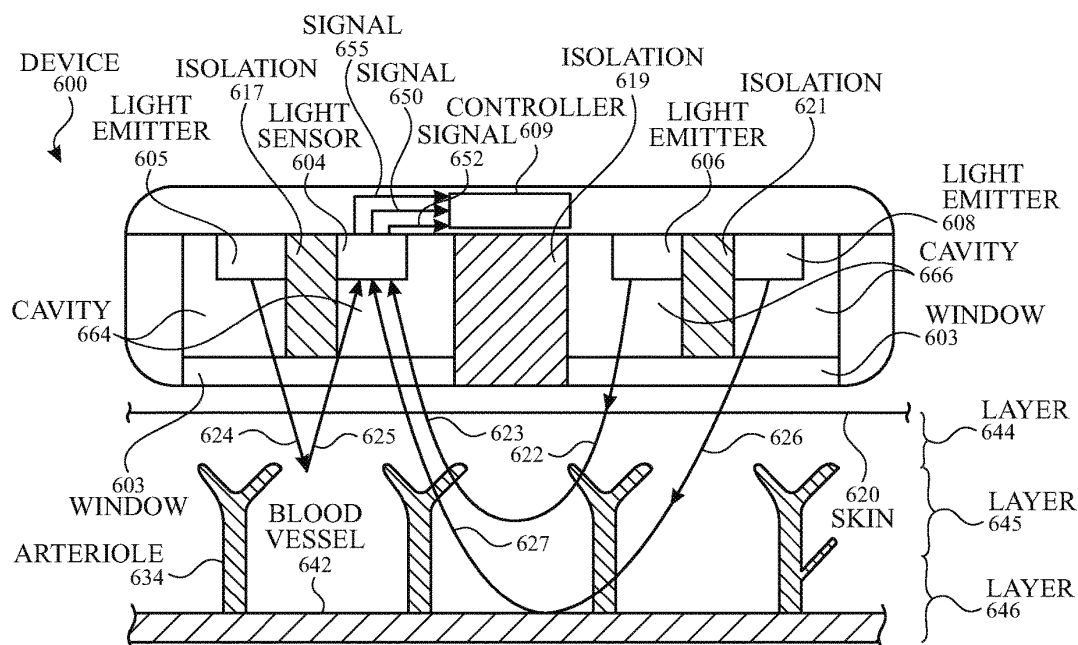


FIG. 6C

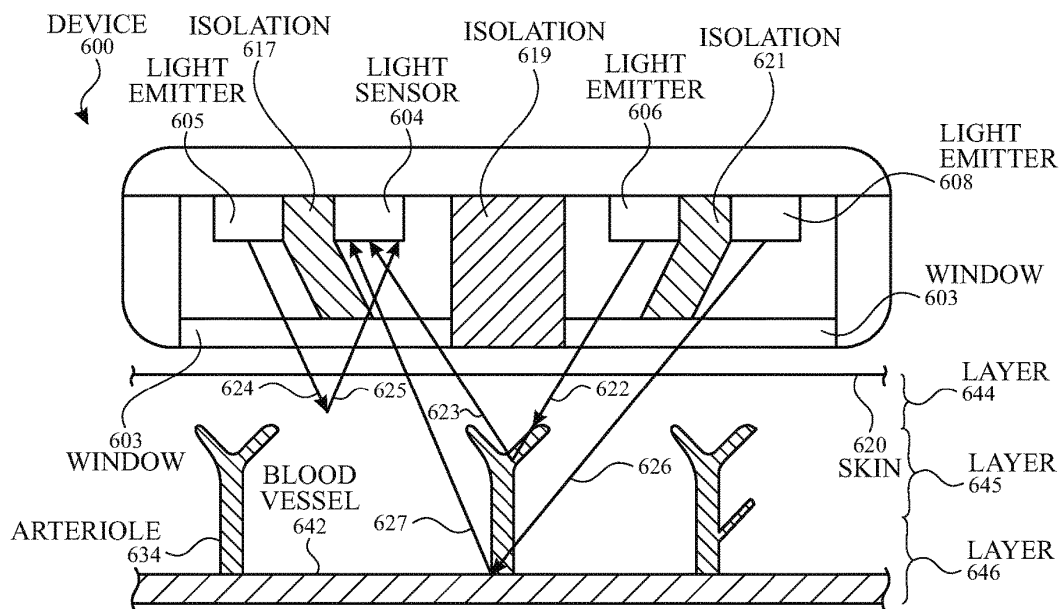


FIG. 6D

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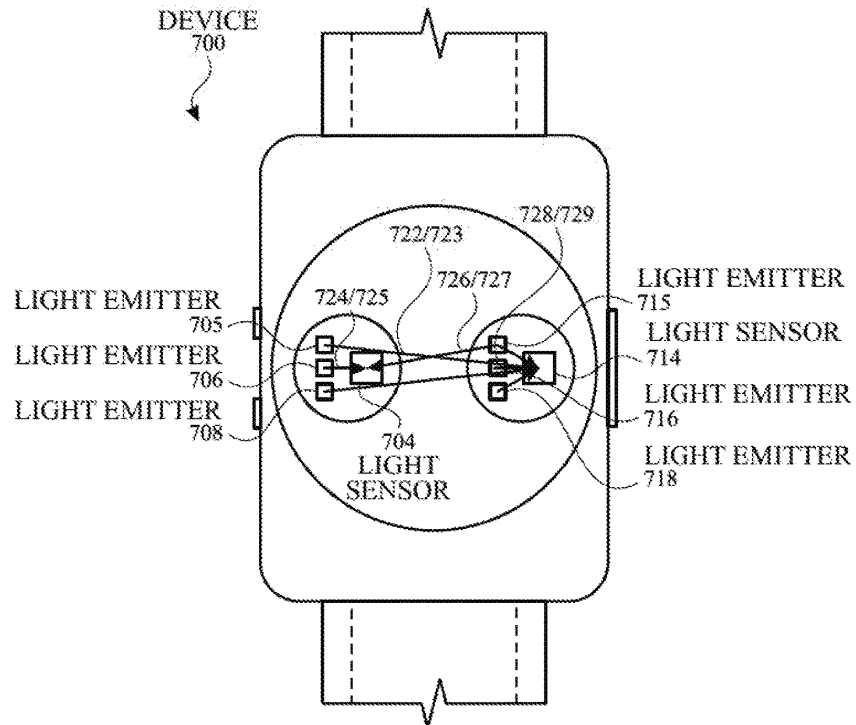


FIG. 7A

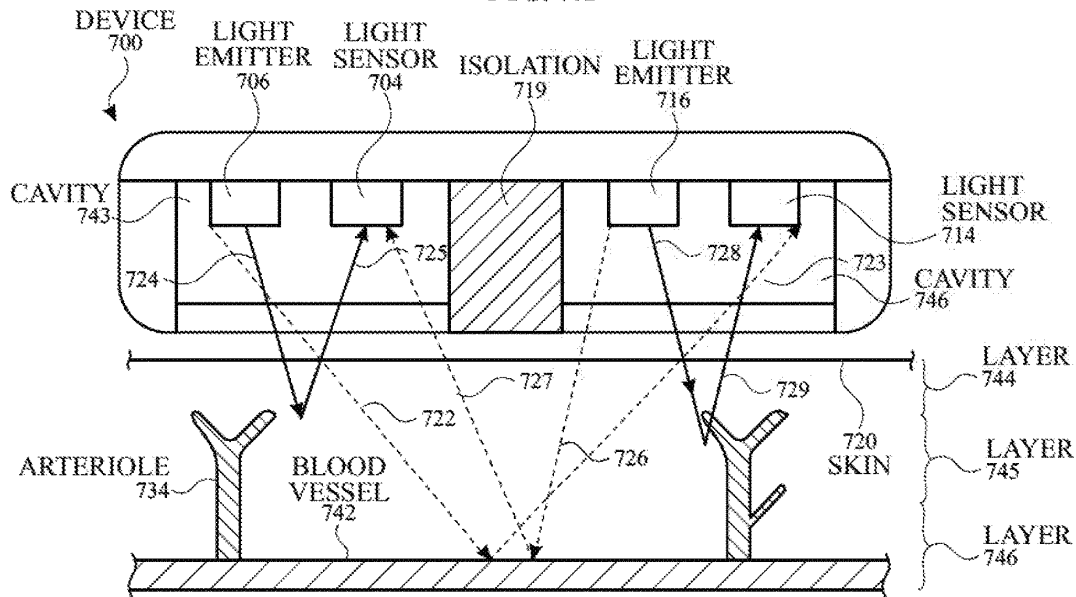


FIG. 7B

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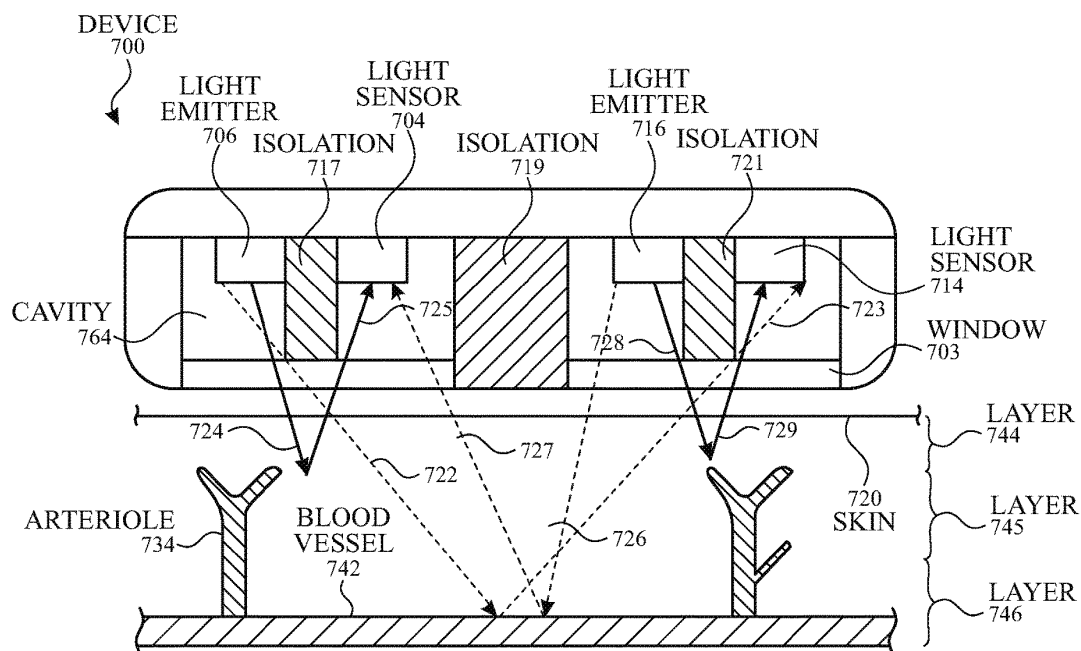


FIG. 7C

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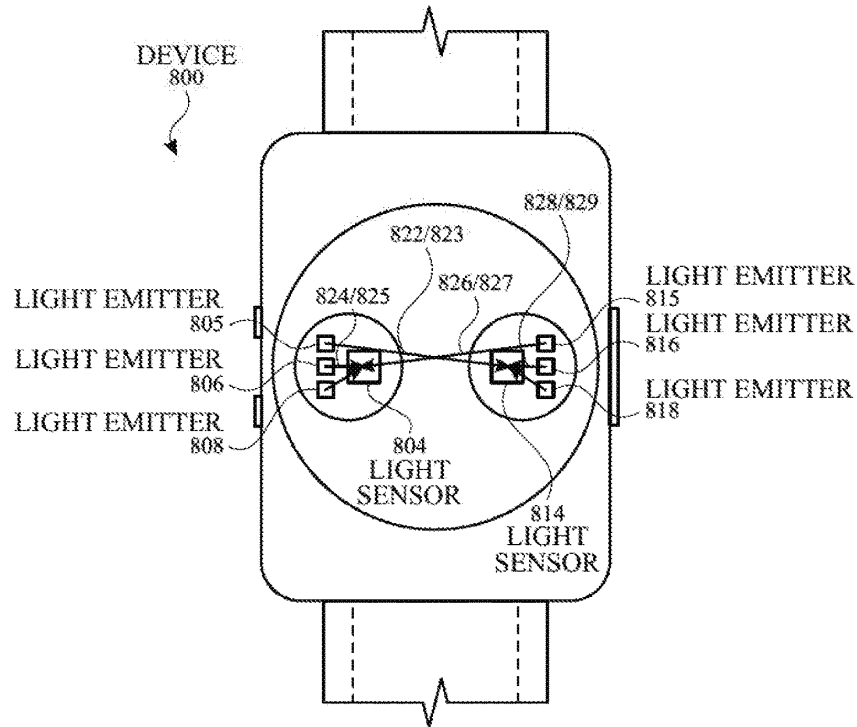


FIG. 8A

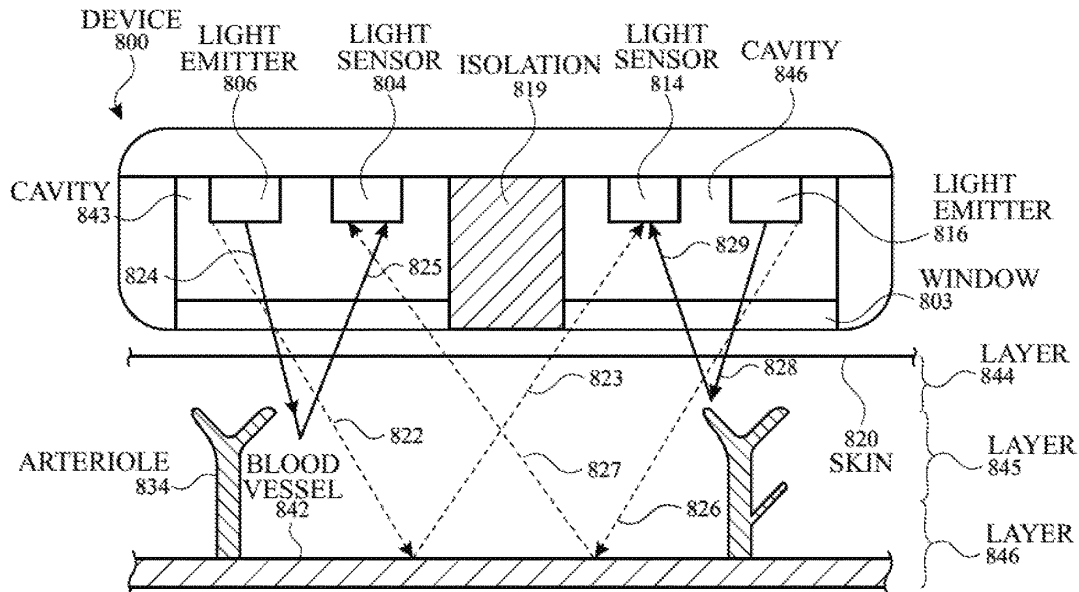


FIG. 8B

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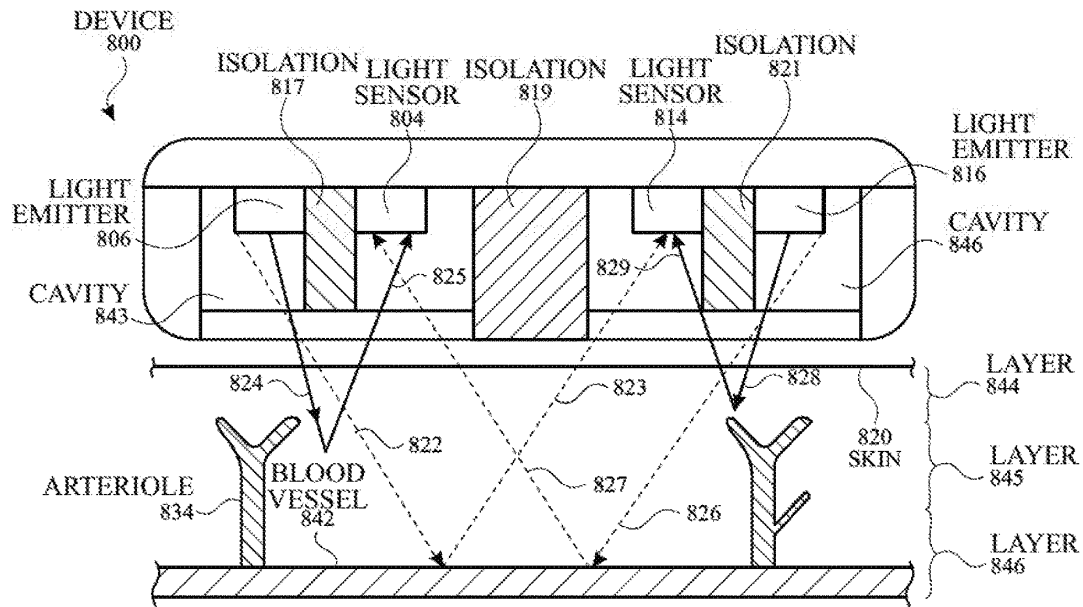


FIG. 8C

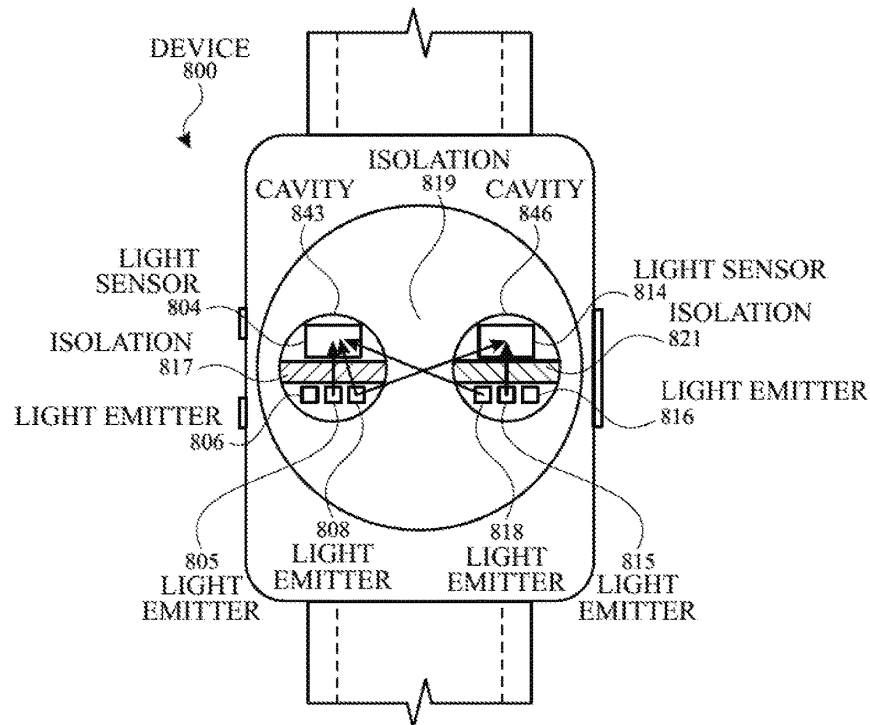


FIG. 8D

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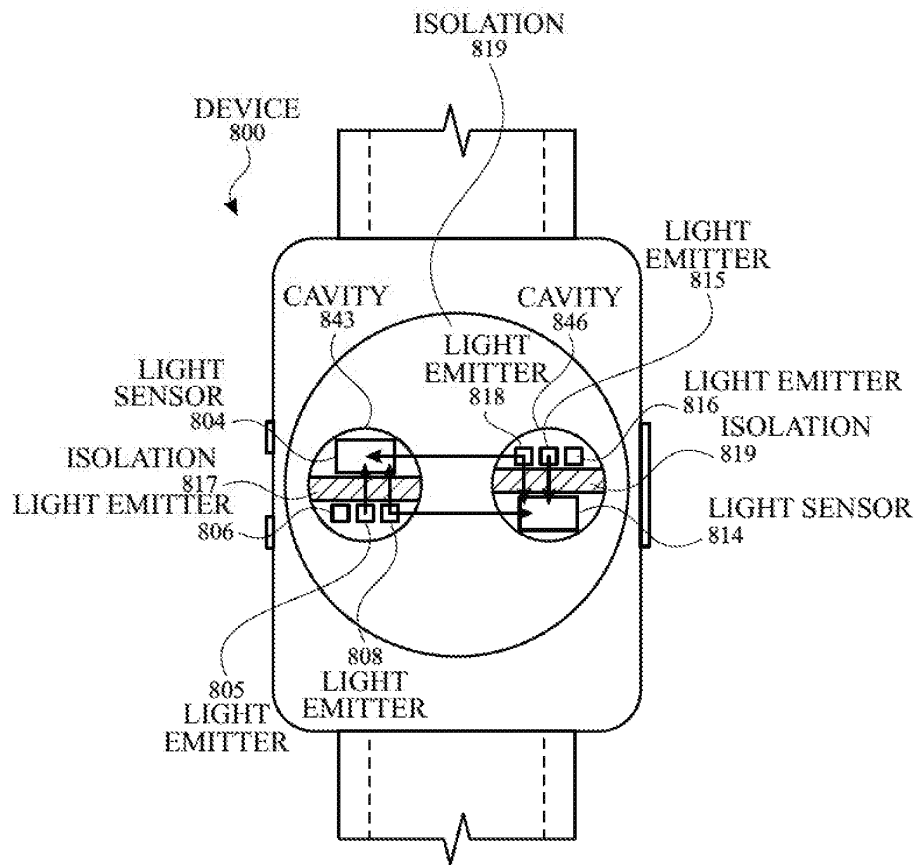


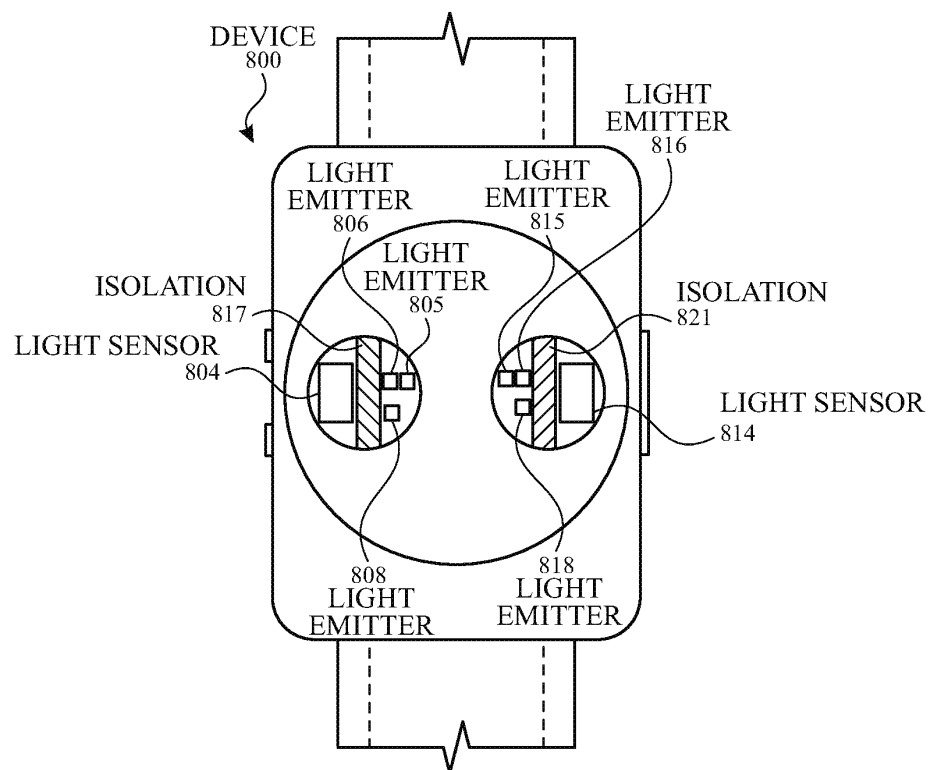
FIG. 8E

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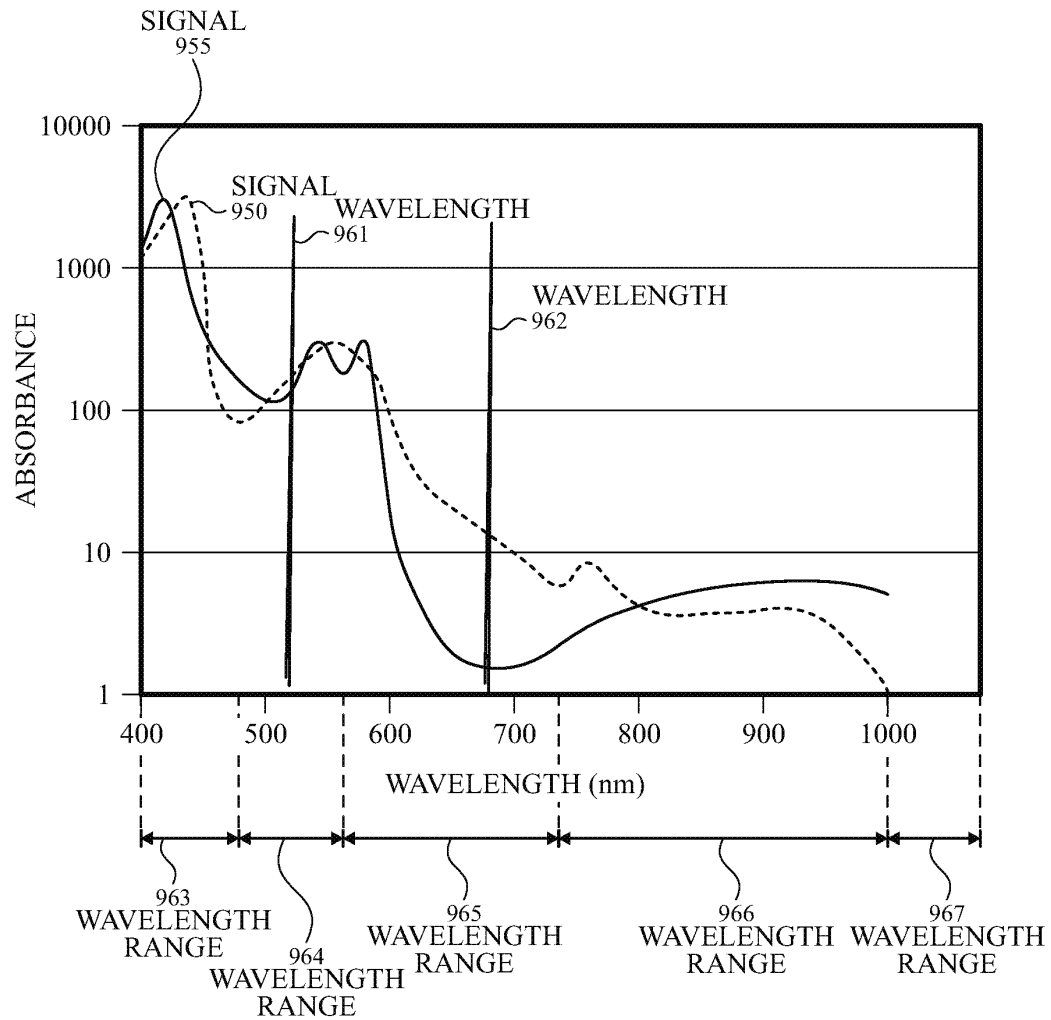
**FIG. 8F**

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**FIG. 9A**

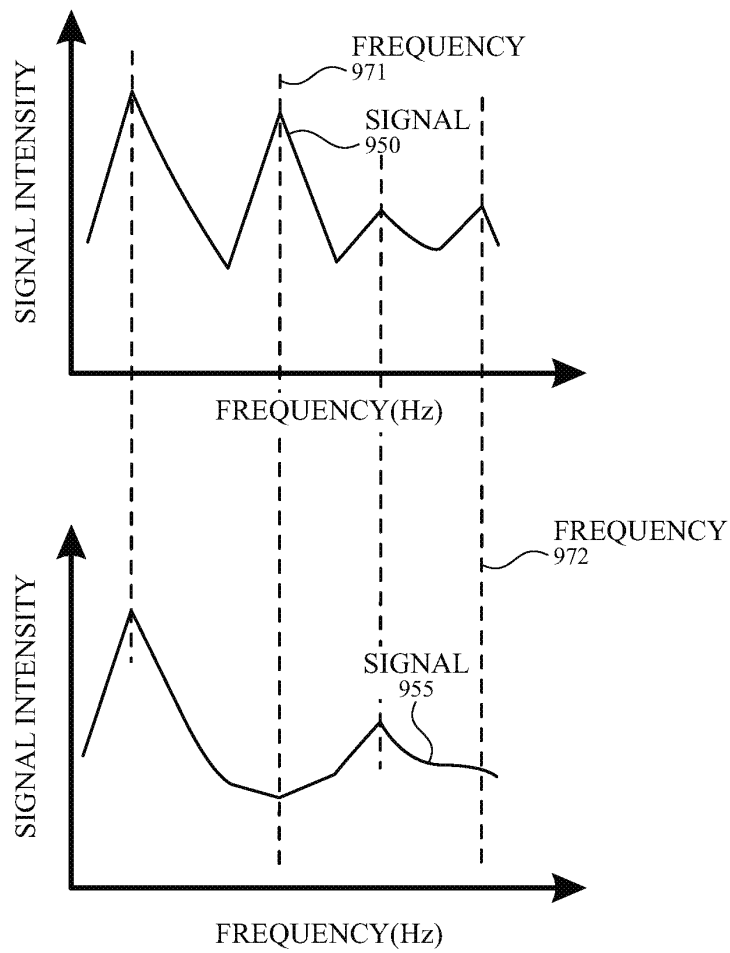


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**FIG. 9B**

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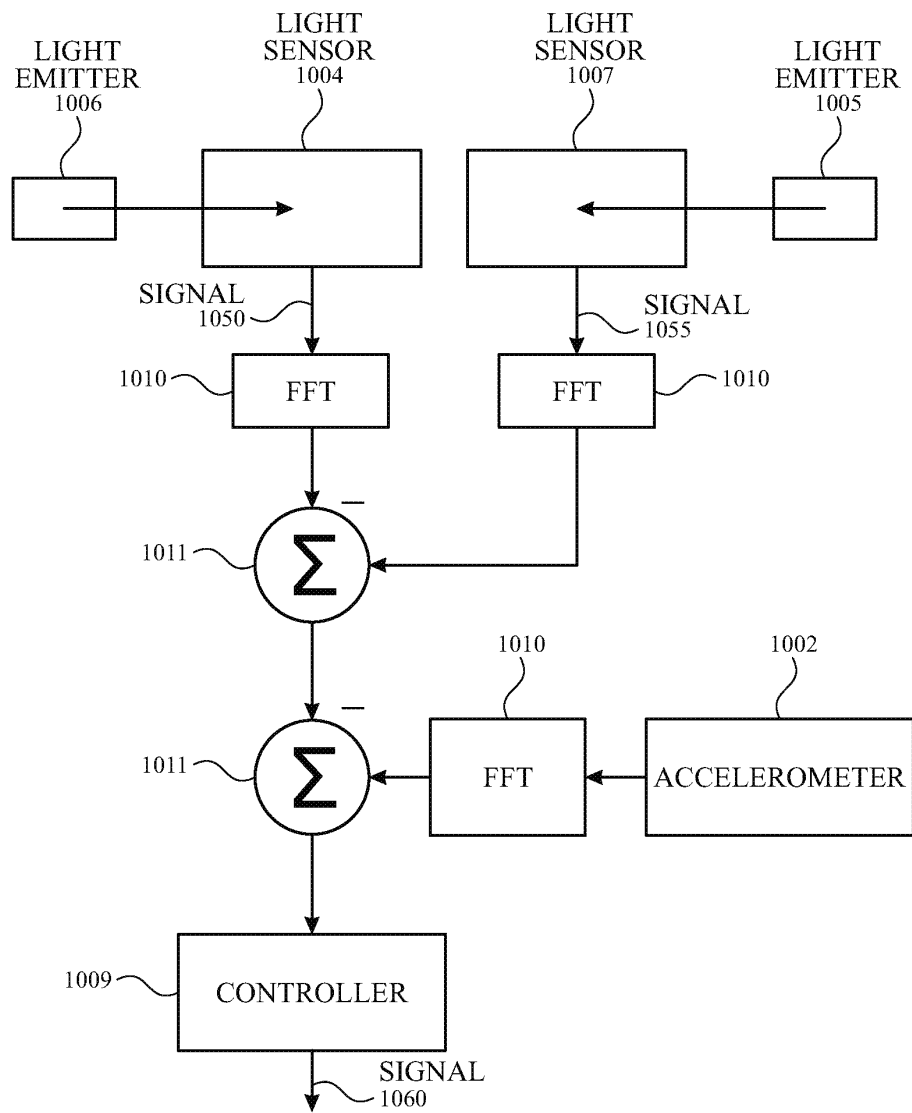


FIG. 10A

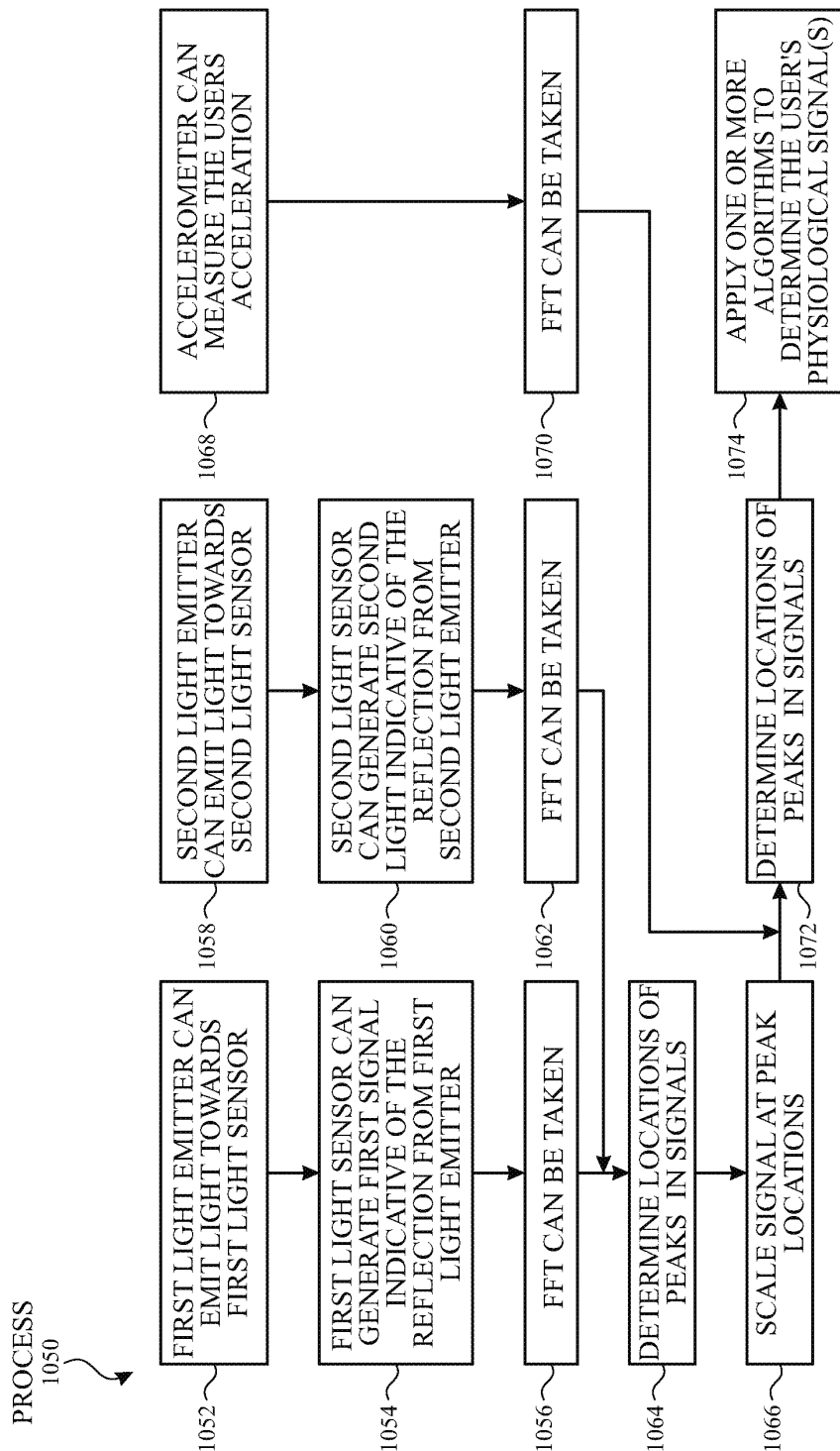


FIG. 10B

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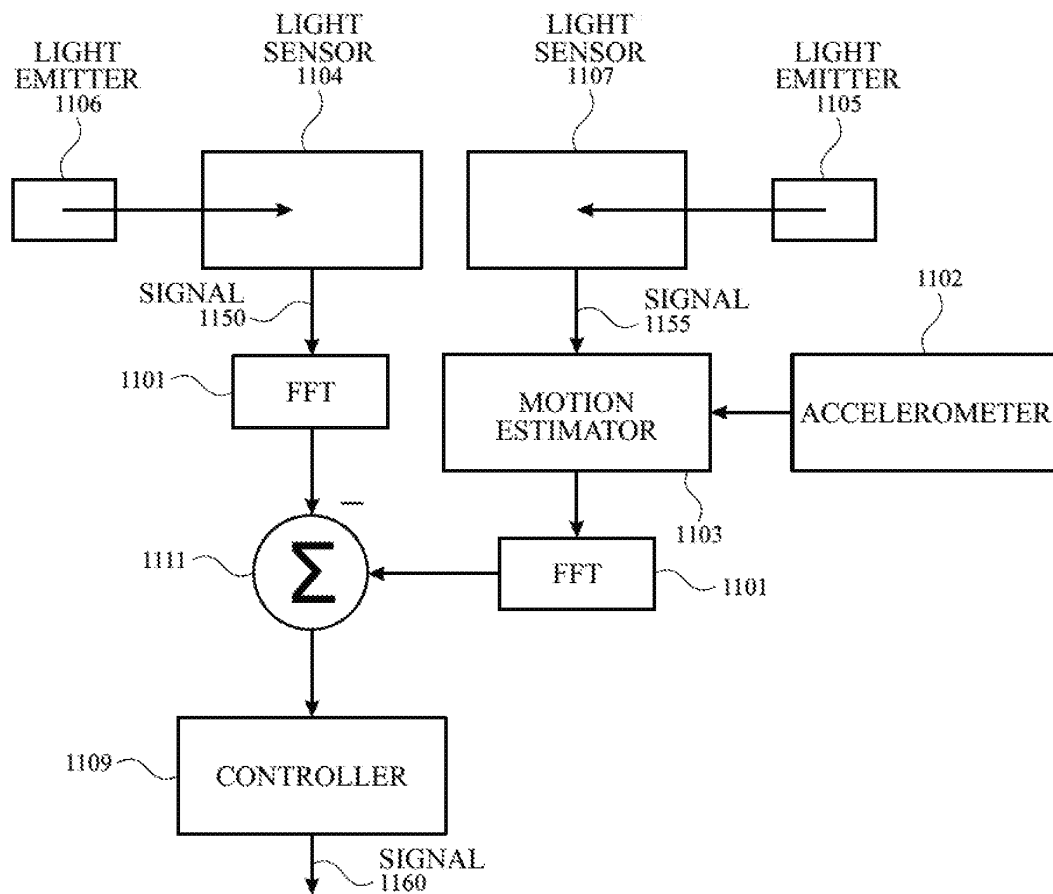


FIG. 11A

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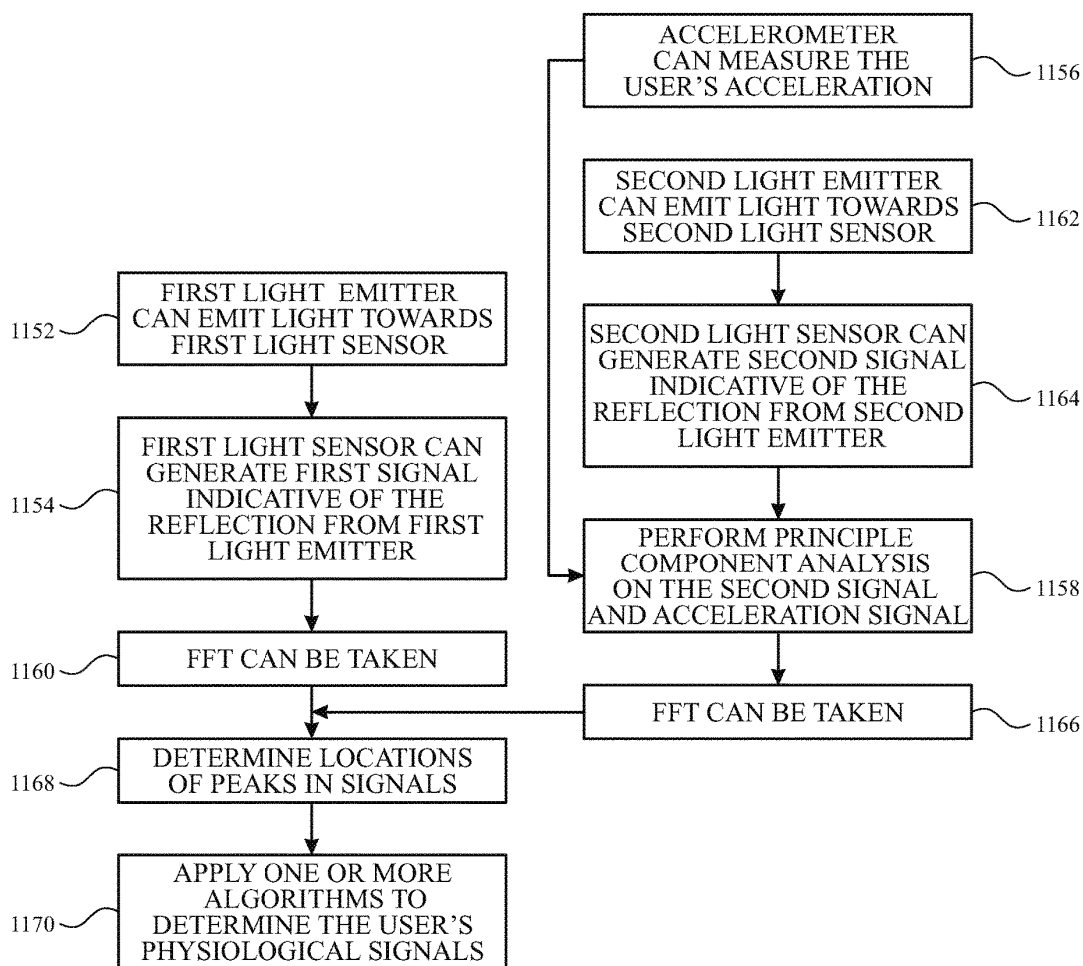


FIG. 11B

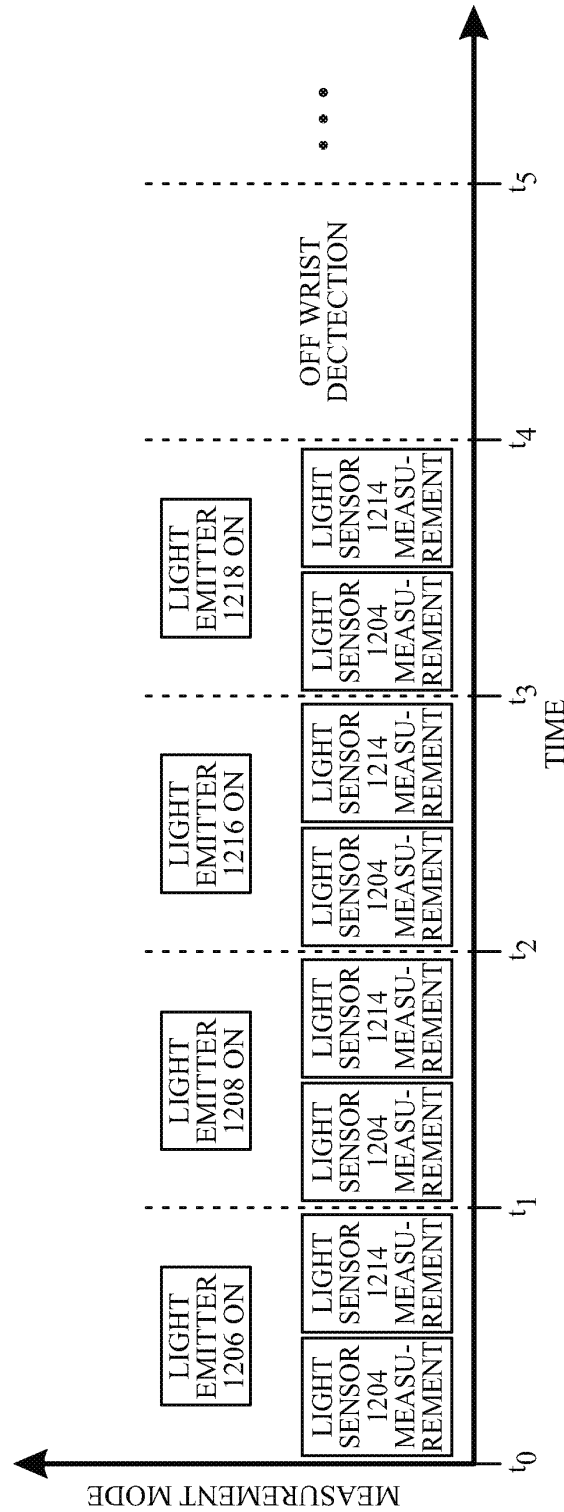


FIG. 12A

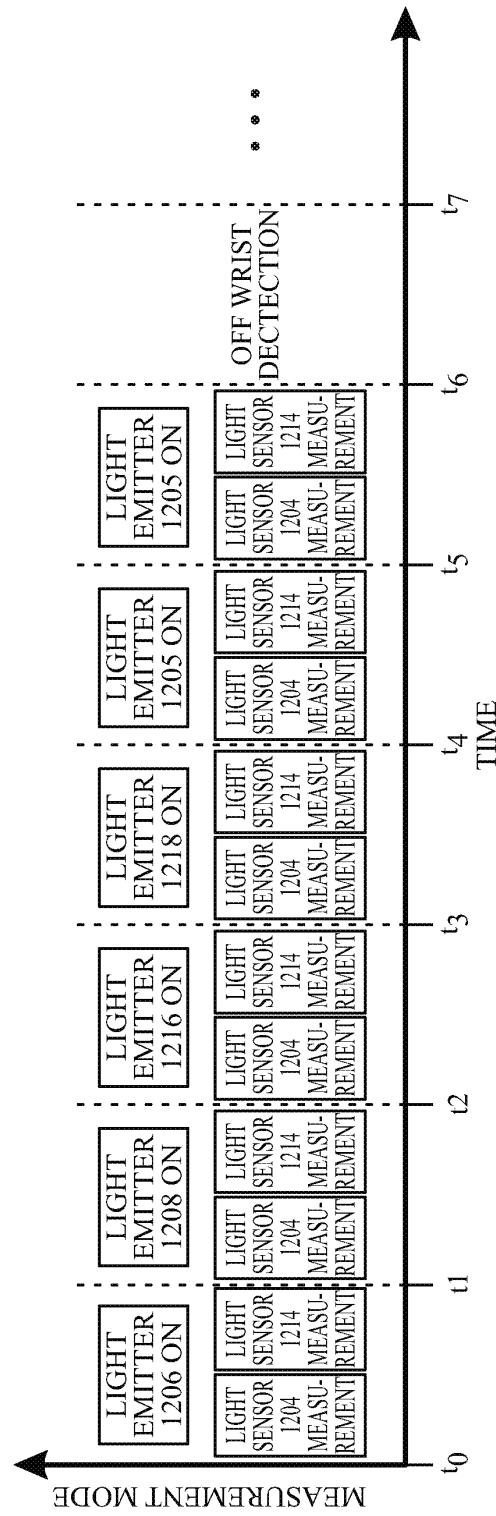


FIG. 12B

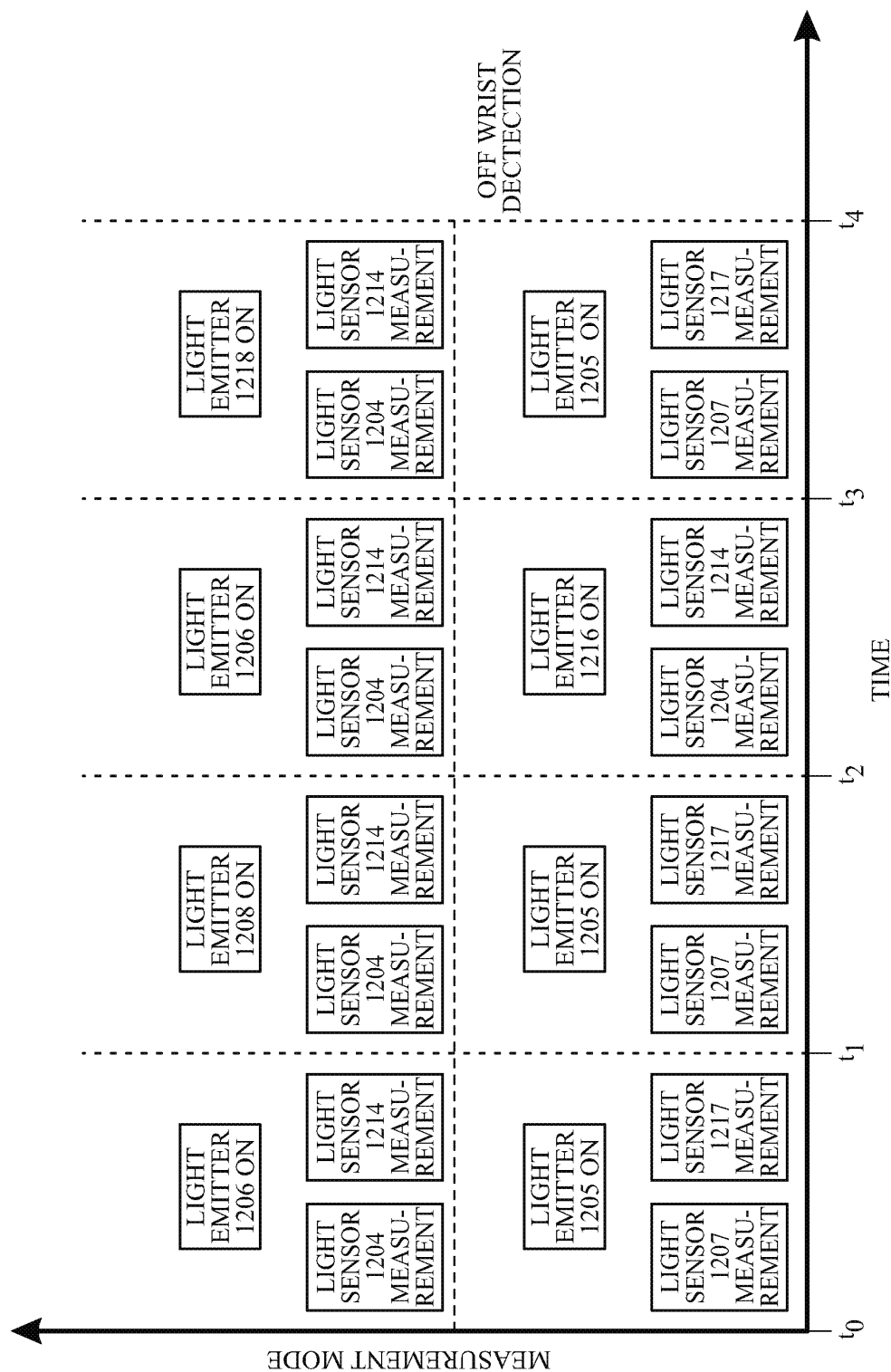


FIG. 12C



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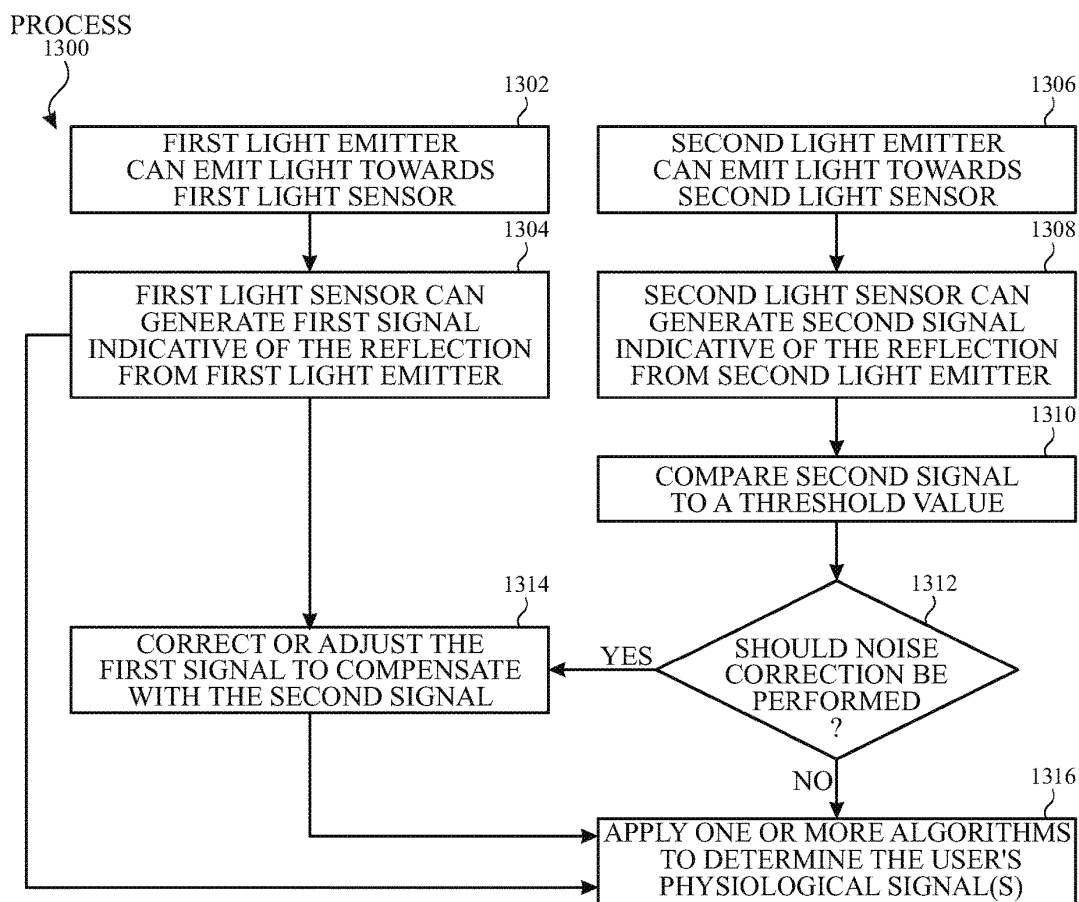


FIG. 13A

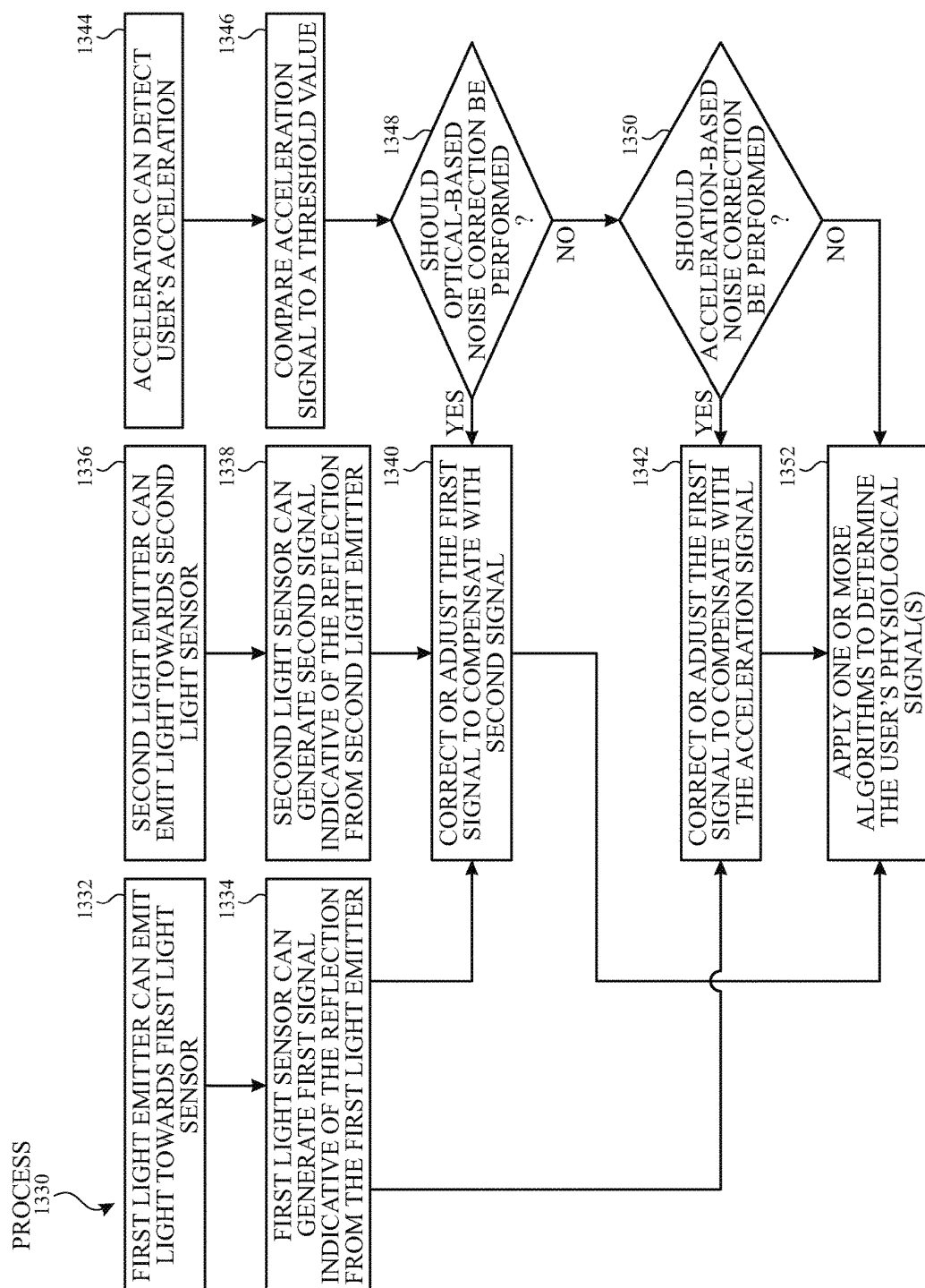


FIG. 13B

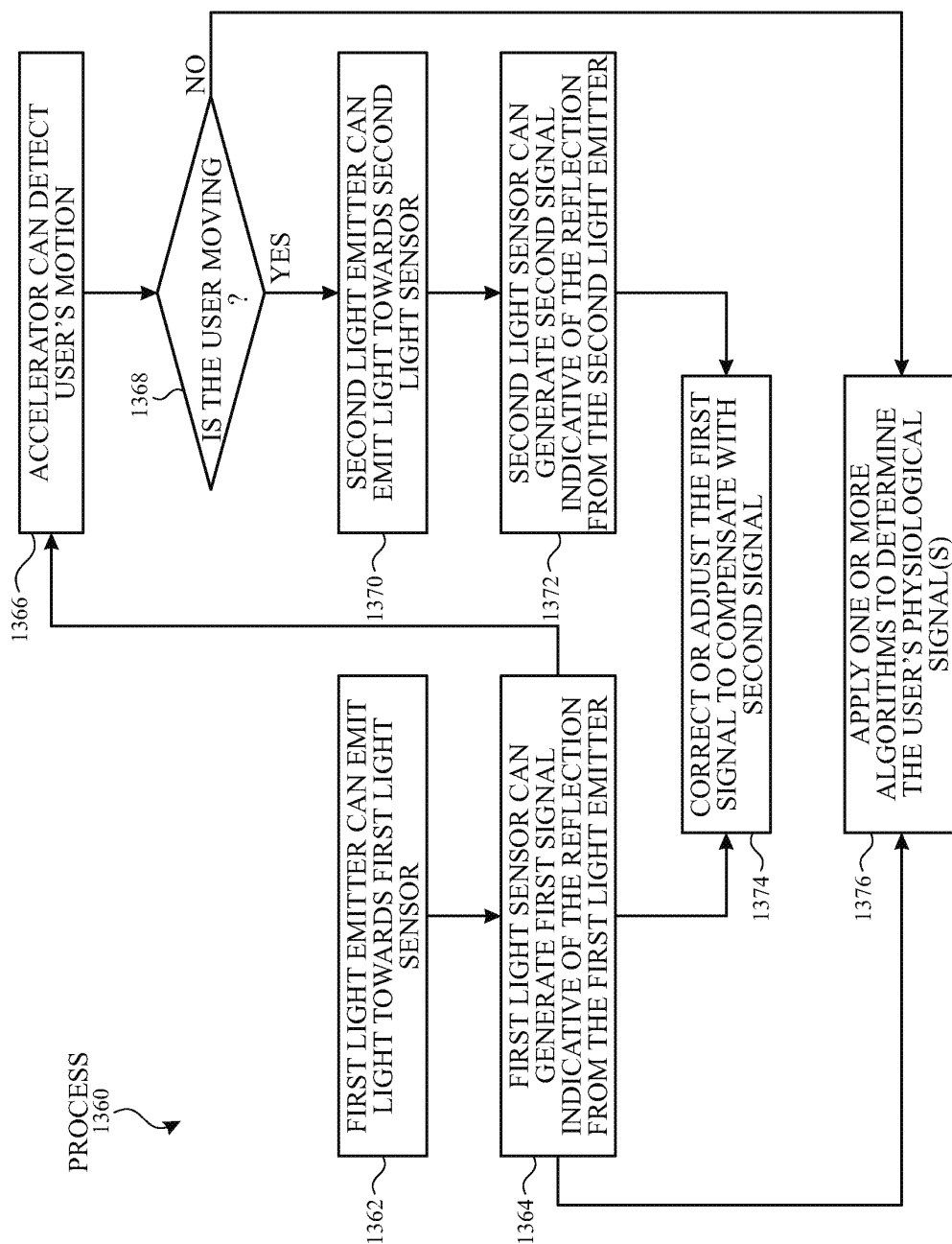


FIG. 13C

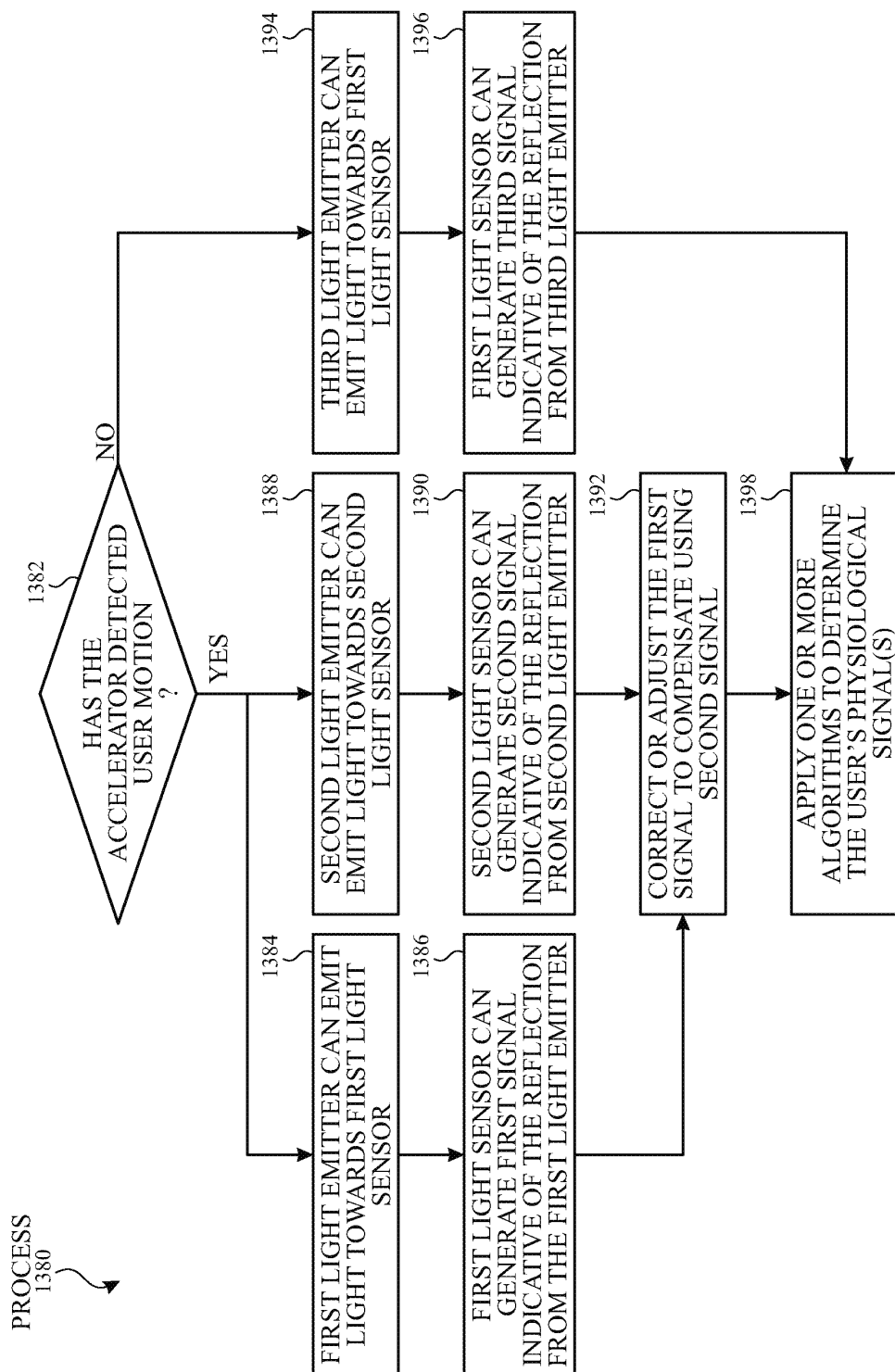


FIG. 13D

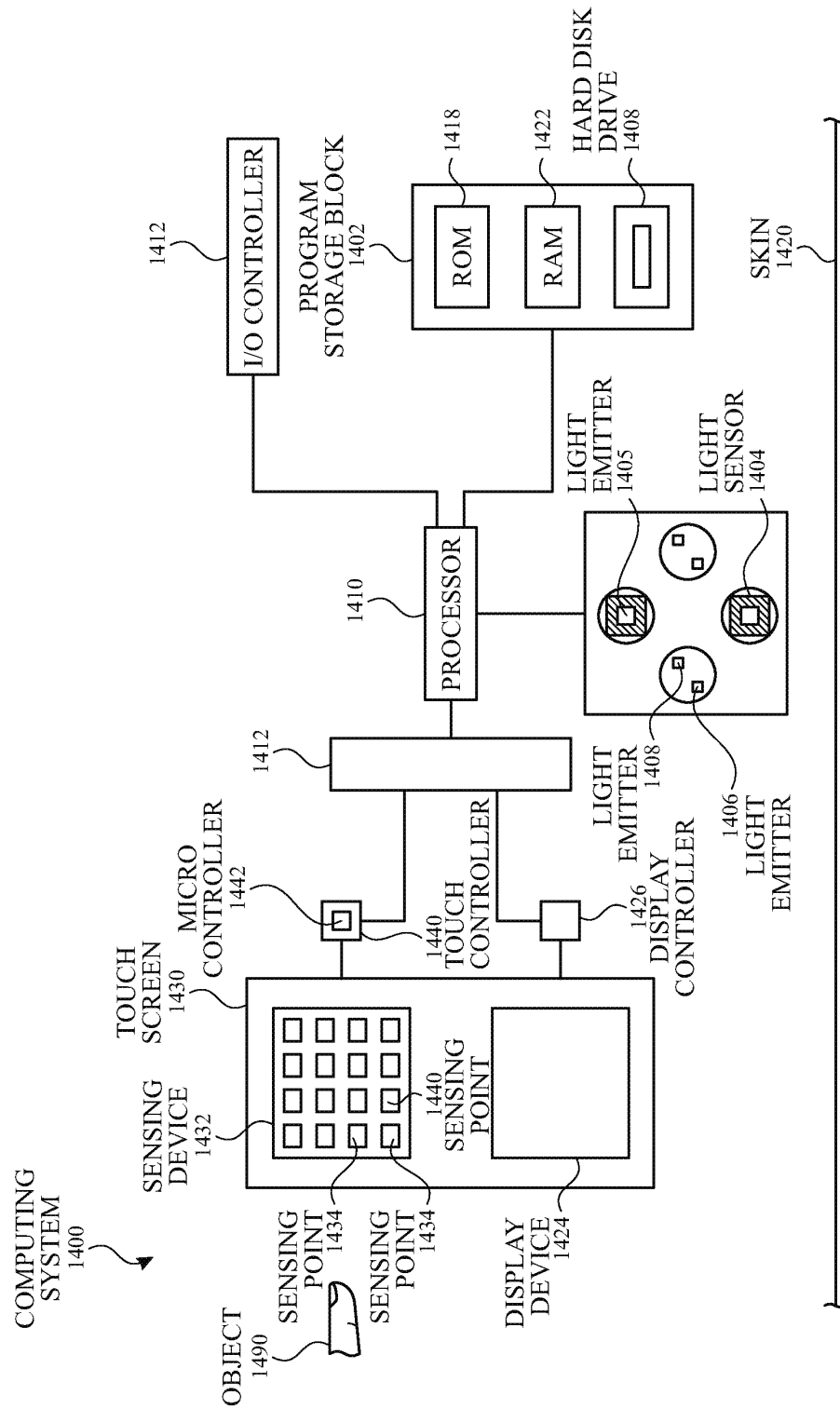


FIG. 14

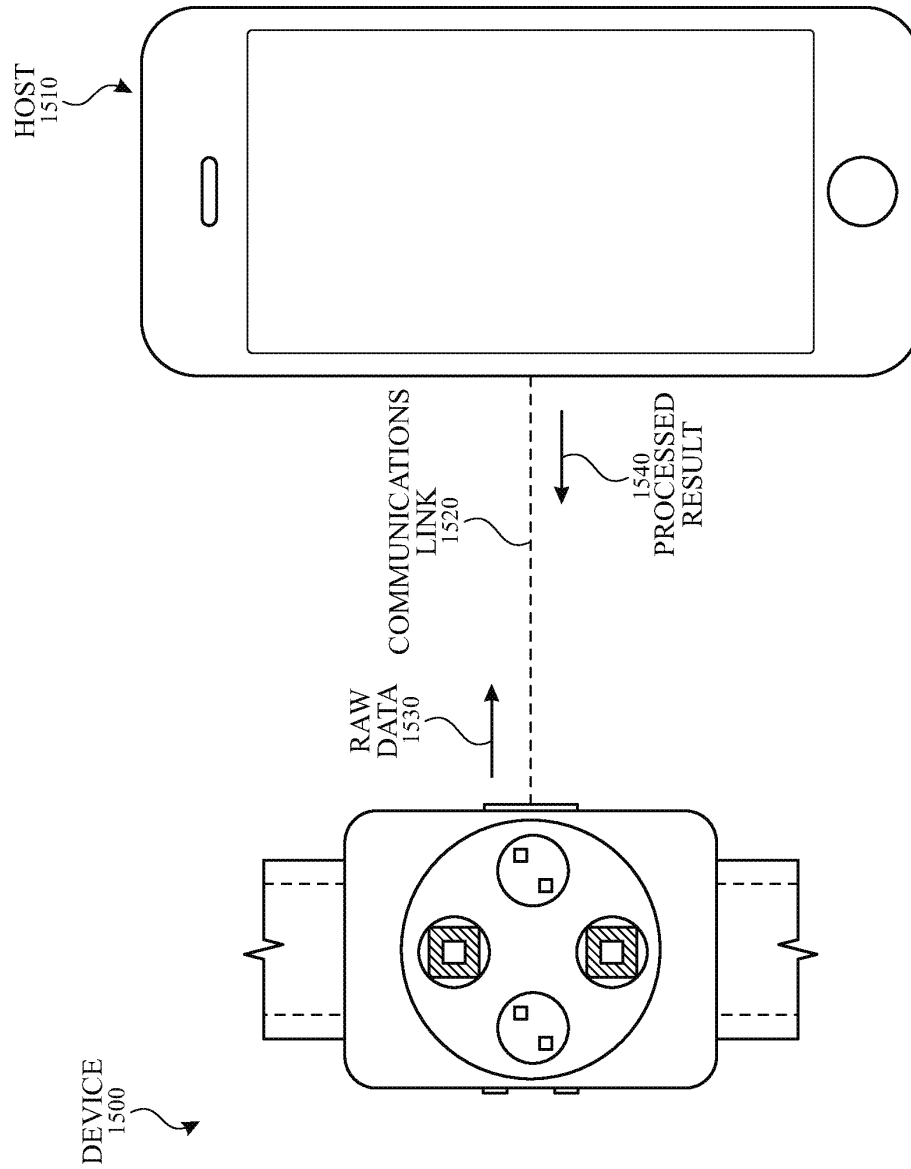


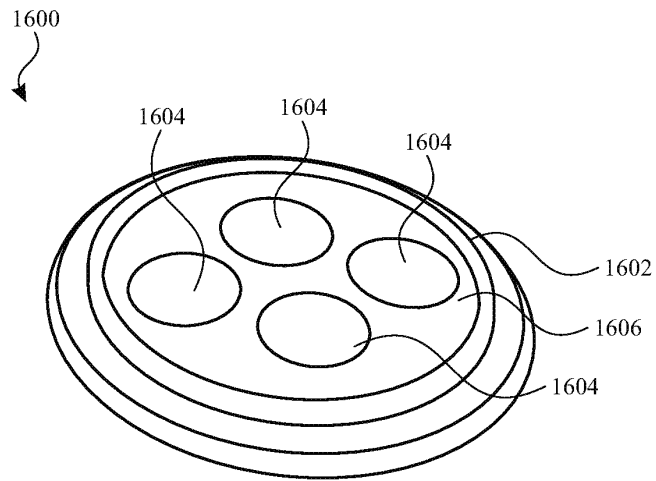
FIG. 15

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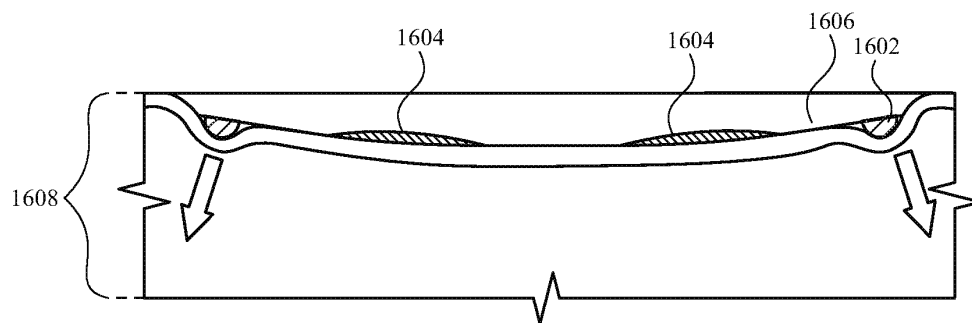
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**FIG. 16A**



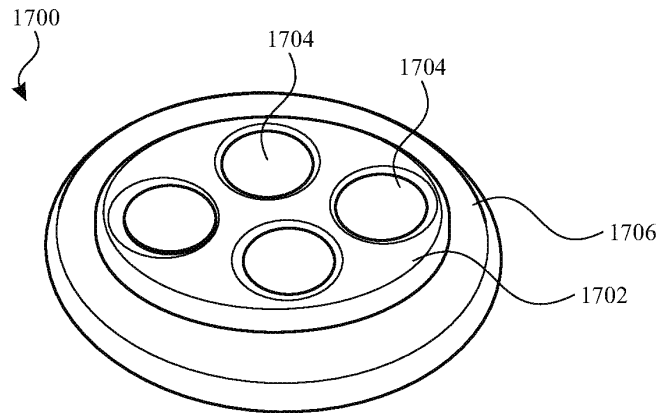
**FIG. 16B**

**U.S. Patent**

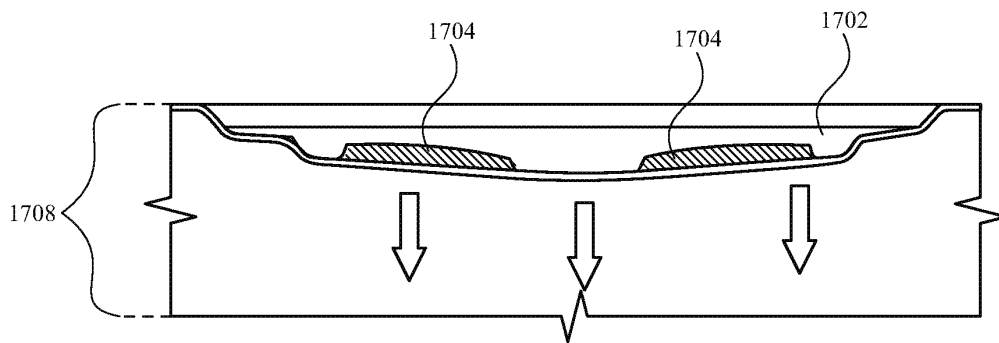
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**FIG. 17A**



**FIG. 17B**

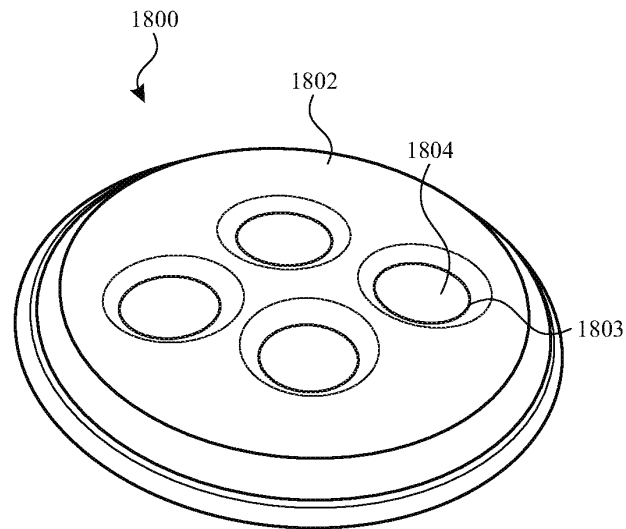


**U.S. Patent**

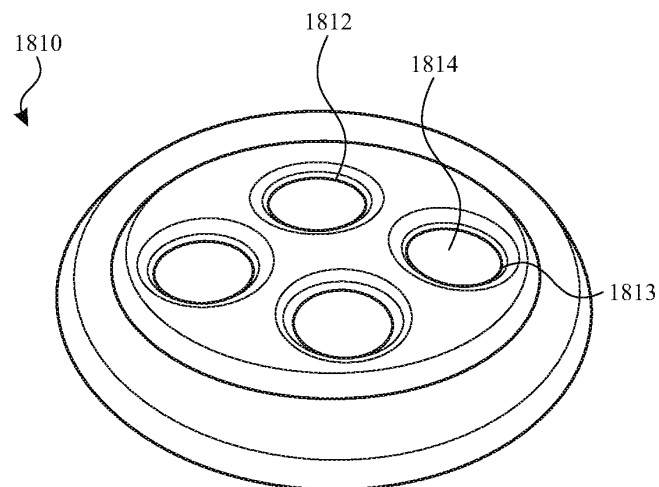
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**FIG. 18A**



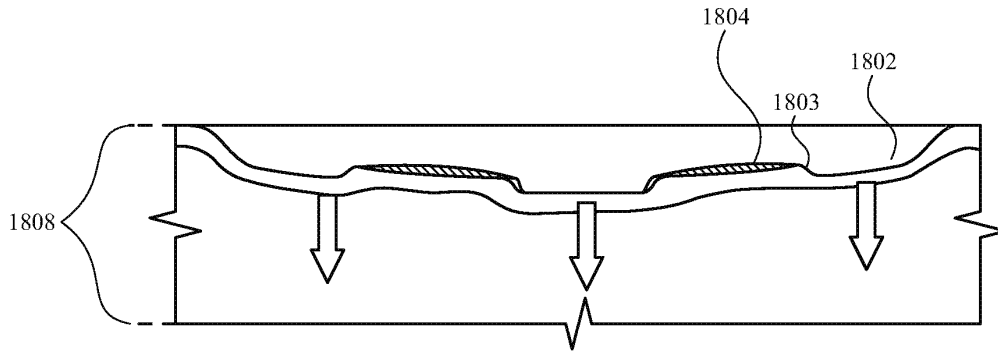
**FIG. 18B**

**U.S. Patent**

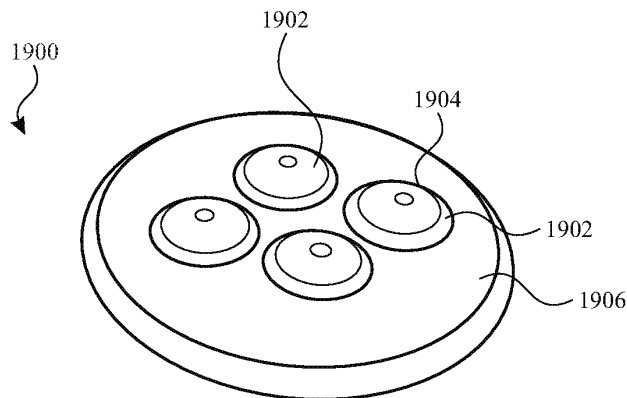
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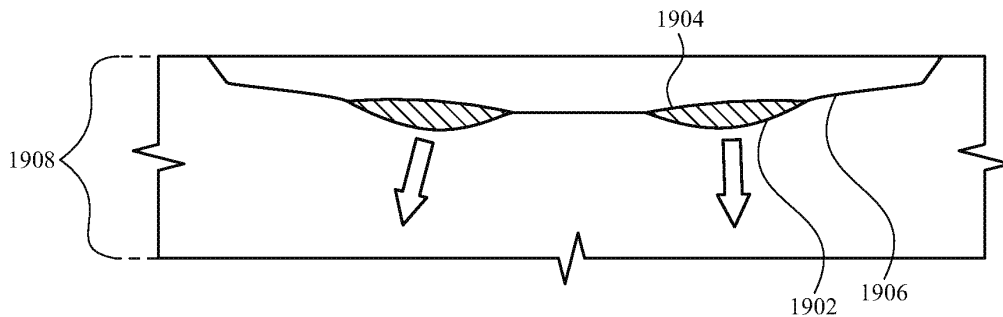
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**FIG. 18C**



**FIG. 19A**



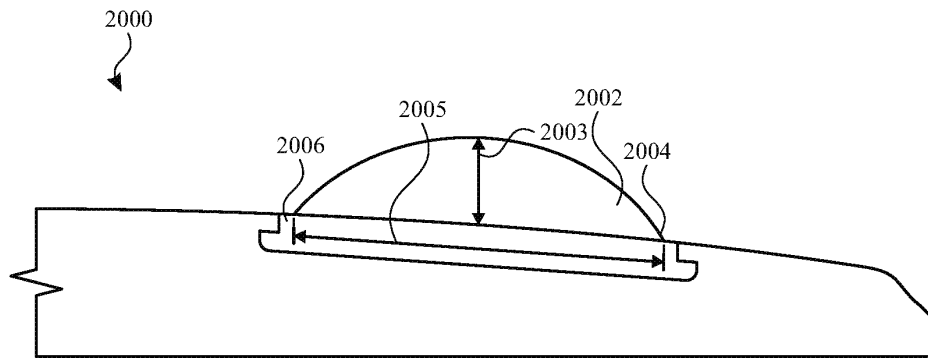
**FIG. 19B**

**U.S. Patent**

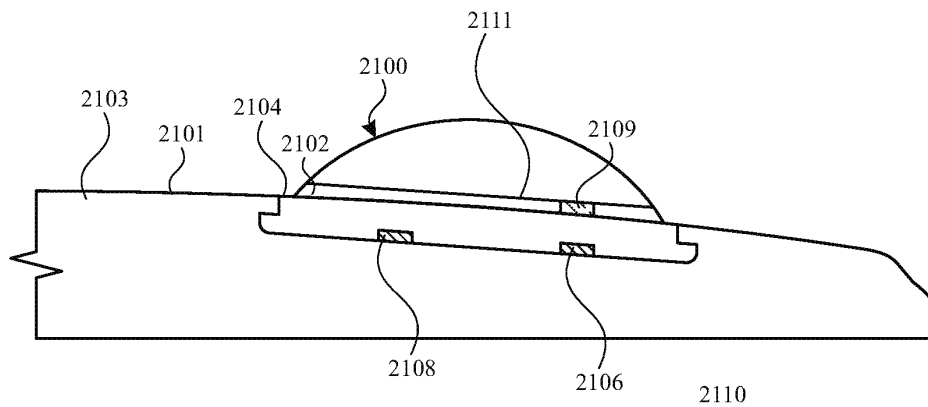
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**FIG. 20**



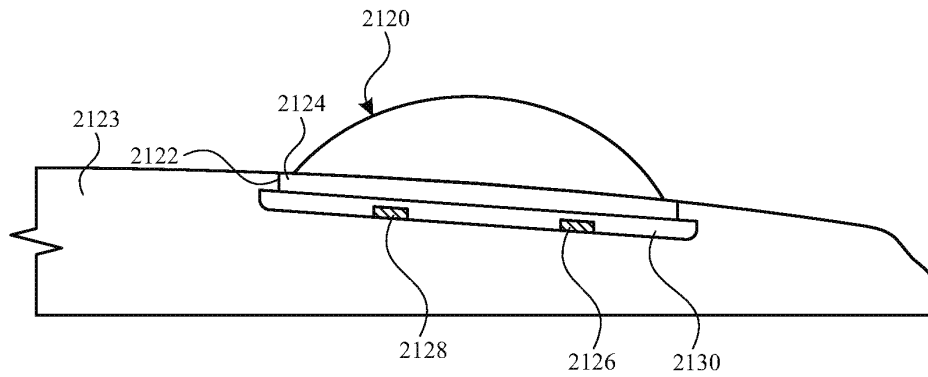
**FIG. 21A**

**U.S. Patent**

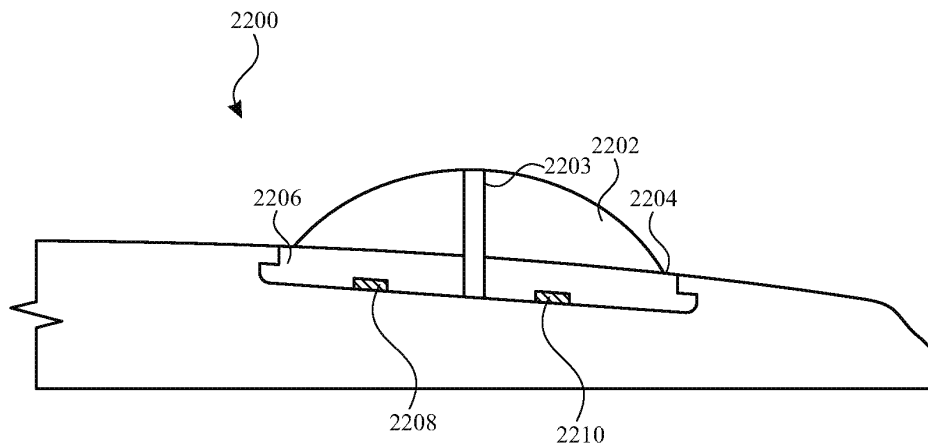
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**FIG. 21B**



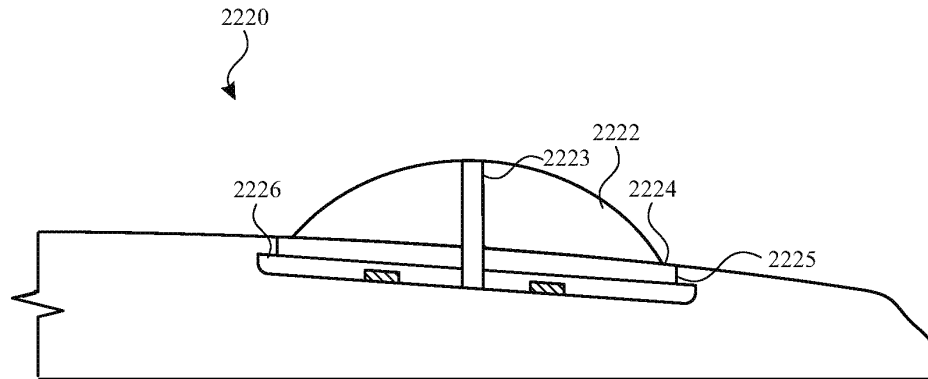
**FIG. 22A**

**U.S. Patent**

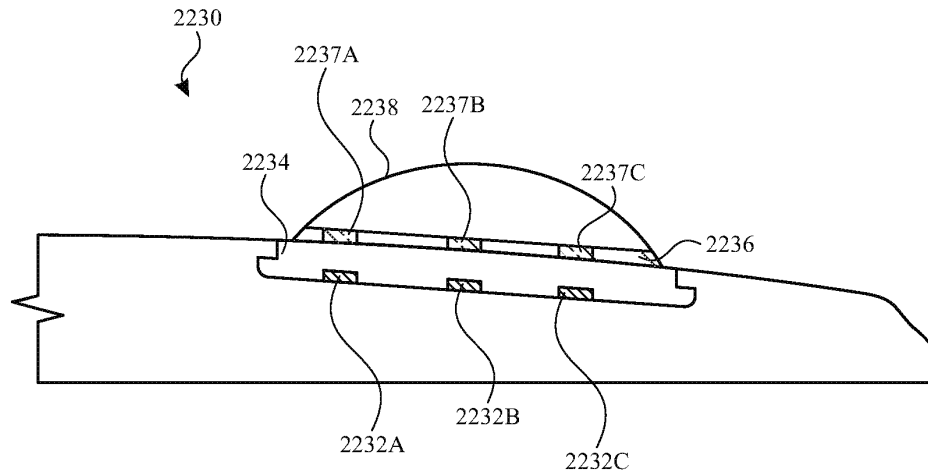
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**FIG. 22B**



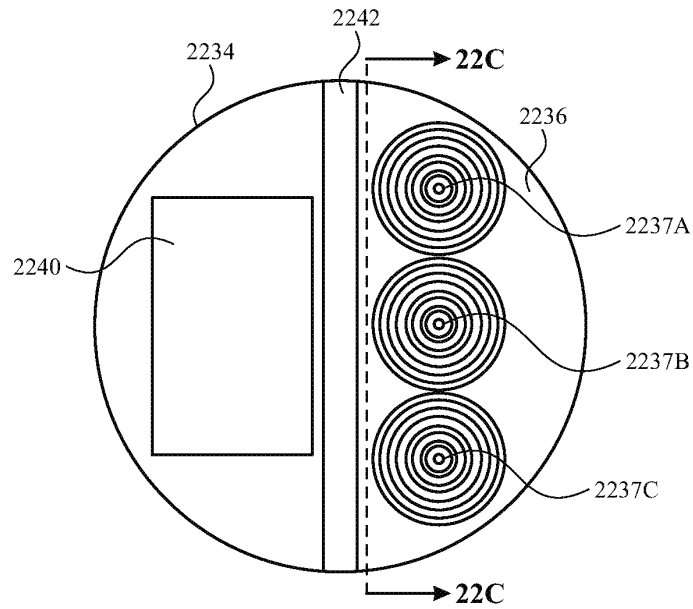
**FIG. 22C**

**U.S. Patent**

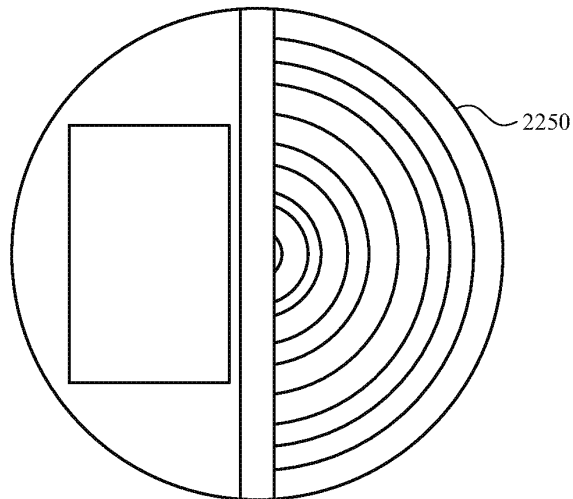
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**FIG. 22D**



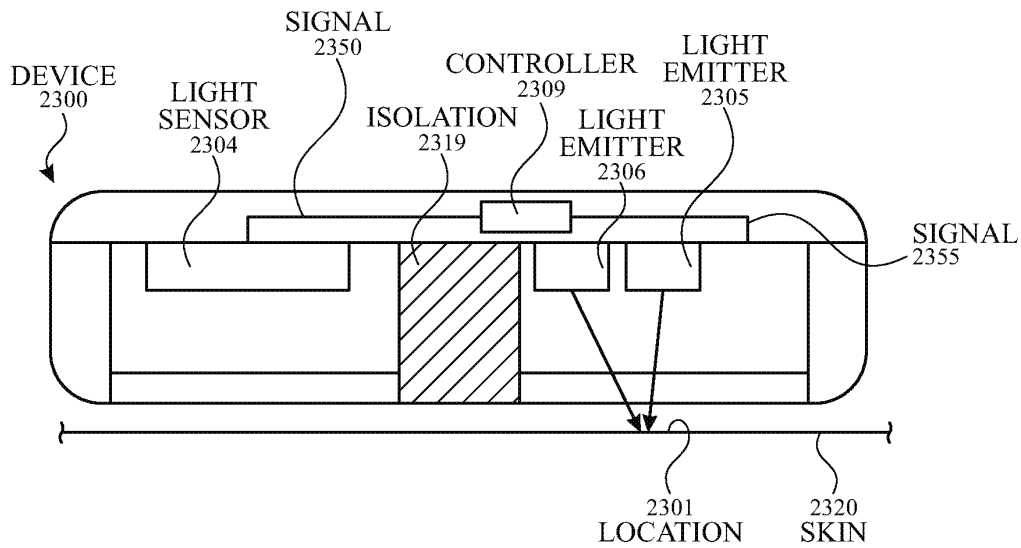
**FIG. 22E**

**U.S. Patent**

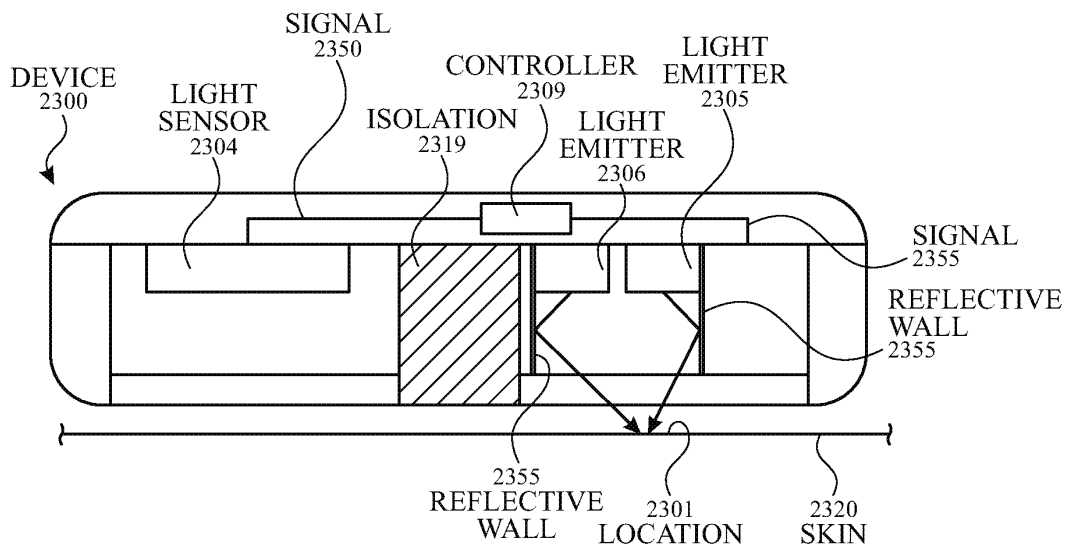
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**FIG. 23A**



**FIG. 23B**

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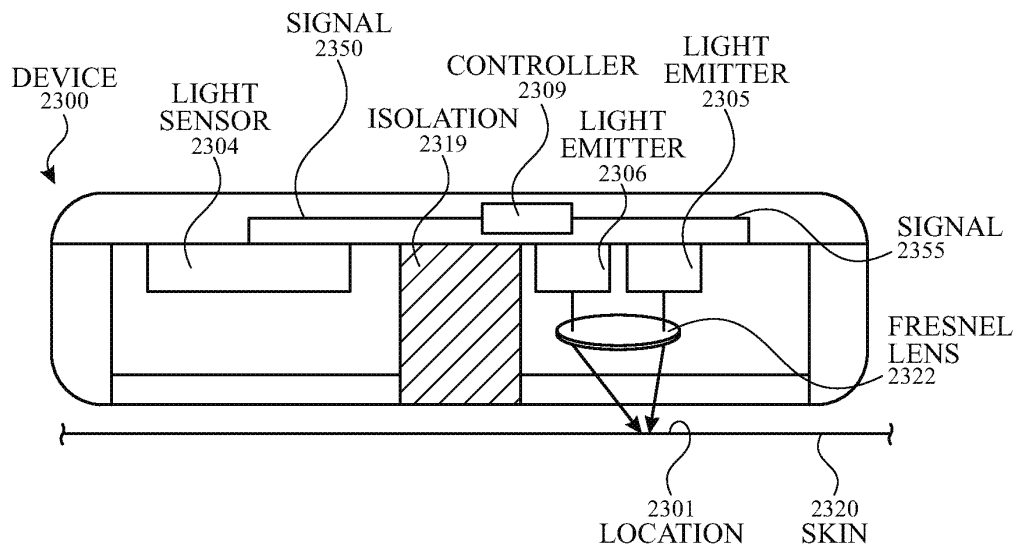


FIG. 23C



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# SYSTEMS AND METHODS FOR NON-PULSATILE BLOOD VOLUME MEASUREMENTS

## CROSS-REFERENCE TO RELATED APPLICATIONS

This application claims priority to U.S. Provisional Patent Application Ser. No. 62/334,363, filed May 10, 2016, which is hereby incorporated by reference in its entirety.

## FIELD

This relates generally to architectures for PPG systems, and, more particularly, to PPG systems capable of generating signals including little-to-no pulsatile blood information and capable of measuring non-pulsatile blood volume changes.

## BACKGROUND

A user's physiological signals (e.g., pulse rate or arterial oxygen saturation) can be determined by photoplethysmogram (PPG) systems. In a basic form, PPG systems can employ one or more light sources that illuminate a user's tissue and one or more light detectors to receive light that enters and probes a subsurface volume of tissue. The light sources and light detectors can be in contact with the tissue or can be remote (i.e., not in contact) to the tissue surface. The received light can include light with an amplitude that can be modulated in time as a result of interaction with pulsatile blood flow and parasitic, non-signal light that can indirectly sample pulsatile tissue volumes with an amplitude that can be modulated (i.e., "noise" or "artifacts") and/or unmodulated (i.e., DC).

Although PPG systems measure the pulsatile blood flow to determine a user's physiological signals, these measurements may be corrupted by noise introduced by, for example, the user's motion, motions from within the user's body (e.g., tendon motion and/or muscle motions that can affect venous blood volume information), tilt and/or pull of the device, ambient light variations, or any combination thereof. While some PPG systems can utilize accelerometer measurements to correct for such noise, accelerometer measurements can be limited to the gross, periodic motion. Given that a user's motion may not be limited to gross, periodic motion, a PPG system capable of differentiating pulsatile blood volume changes from anatomical motion can be desired. In some examples, anatomical motion can be measured by measuring non-pulsatile blood volume changes.

## SUMMARY

This relates to systems and methods for determining one or more of a user's physiological signals. The one or more of the user's physiological signals can be determined by measuring pulsatile blood volume changes. Motion artifacts included in the signals can be canceled or reduced by measuring non-pulsatile blood volume changes and adjusting the signal to account for the non-pulsatile blood information. Non-pulsatile blood volume changes can be measured using at least one set of light emitter-light sensor. The light emitter can be located in close proximity (e.g., less than or equal to 1 mm away) to the light sensor and/or emitting light at specific wavelengths (e.g., greater than 600 nm), thereby limiting light emitted by the light emitter to inter-

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action to venous blood (non-pulsatile blood) volume changes. In some examples, the systems can further include an accelerometer configured to measure the user's acceleration, and the acceleration signal can be additionally be used for compensating of motion artifacts.

## BRIEF DESCRIPTION OF THE DRAWINGS

FIGS. 1A-1C illustrate systems in which examples of the disclosure can be implemented

FIG. 2A illustrates a top view of an exemplary electronic device including light sensors and light emitters for measuring a user's physiological signal according to examples of the disclosure.

FIG. 2B illustrates a cross-sectional view of an exemplary electronic device including light sensors and light emitters for measuring a user's physiological signal according to examples of the disclosure.

FIG. 3A illustrates a top view of an exemplary electronic device including light sensors and light emitters for measuring a user's physiological signal according to examples of the disclosure.

FIG. 3B illustrates a cross-sectional view of an exemplary electronic device including light sensors and light emitters for measuring a user's physiological signal according to examples of the disclosure.

FIG. 3C illustrates exemplary circuitry coupled to the light sensors and light emitters and utilized for estimation of the user's physiological signals according to examples of the disclosure.

FIG. 3D illustrates an exemplary process flow for estimating the user's physiological signals according to example of the disclosure.

FIG. 4A illustrates a top view of an exemplary electronic device including a dedicated sensor and light emitter set for noise correction utilized in measuring a user's physiological signal according to examples of the disclosure.

FIG. 4B illustrates a cross-sectional view of an exemplary electronic device including a dedicated light sensor and light emitter set for noise correction utilized in measuring a user's physiological signal according to examples of the disclosure.

FIGS. 4C-4D illustrate cross-sectional views of exemplary electronic devices including a light sensor optically coupled to a light emitter in the same cavity, but divided by an isolation according to examples of the disclosure.

FIG. 5A illustrates a top view of an exemplary electronic device including at least one separate light sensor and light emitter set for noise correction utilized in measuring a user's physiological signal according to examples of the disclosure.

FIG. 5B illustrates a cross-sectional view of an exemplary electronic device including at least one separate light sensor and light emitter set for noise correction utilized in measuring a user's physiological signal according to examples of the disclosure.

FIG. 5C illustrates a cross-sectional view of an exemplary electronic device including a light sensor optically coupled to a light emitter in the same cavity, but divided by an isolation according to examples of the disclosure.

FIG. 6A illustrates a top view of an exemplary electronic device including a light sensor optically coupled to a common light emitter used for noise correction utilized in measuring a user's physiological signal according to examples of the disclosure.

FIG. 6B illustrates a cross-sectional view of an exemplary electronic device including a light sensor optically coupled

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to a common light emitter used for noise correction utilized in measuring a user's physiological signal according to examples of the disclosure.

FIG. 6C illustrates a cross-sectional view of an exemplary electronic device including a light sensor optically coupled to a common light emitter used for noise correction utilized in measuring a user's physiological signal according to examples of the disclosure.

FIG. 6D illustrates a cross-sectional view of an exemplary electronic device including angled isolation according to examples of the disclosure.

FIG. 7A illustrates a top view of an exemplary electronic device including at least two different cavities, each cavity can include at least one light sensor and a plurality of light emitters according to examples of the disclosure.

FIG. 7B illustrates a cross-sectional view of an exemplary electronic device including at least two different cavities, each cavity can include at least one light sensor and a plurality of light emitters according to examples of the disclosure.

FIG. 7C illustrates a cross-sectional view of an exemplary electronic device including at least two different cavities, each cavity including at least one light sensor and a plurality of light emitters divided by an isolation according to examples of the disclosure.

FIG. 8A illustrates a top view of an exemplary electronic device including at least two different cavities, each cavity including at least one light sensor and a plurality of light emitters according to examples of the disclosure.

FIG. 8B illustrates a cross-sectional view of an exemplary electronic device including at least two different cavities, each cavity including at least one light sensor and a plurality of light emitters according to examples of the disclosure.

FIG. 8C illustrates a cross-sectional view of an exemplary electronic device including at least two different cavities, each cavity including at least one light sensor and a plurality of light emitters divided by an isolation according to examples of the disclosure.

FIGS. 8D-8F illustrate top views of exemplary configurations for light emitters, light sensors, and isolation for electronic devices according to examples of the disclosure.

FIG. 9A illustrates exemplary oxy-hemoglobin and deoxy-hemoglobin absorption signals measured across a plurality of wavelengths according to examples of the disclosure.

FIG. 9B illustrates exemplary signals measured at the plurality of light sensors included in an exemplary electronic device according to examples of the disclosure.

FIG. 10A illustrates an exemplary circuit diagram for motion artifact removal according to examples of the disclosure.

FIG. 10B illustrates an exemplary process for motion artifact removal according to examples of the disclosure.

FIG. 11A illustrates an exemplary circuit diagram for motion artifact removal according to examples of the disclosure.

FIG. 11B illustrates an exemplary process for motion artifact removal according to examples of the disclosure.

FIGS. 12A-12C illustrate exemplary measurement modes according to examples of the disclosure.

FIG. 13A illustrates an exemplary process illustrating time-based operation of a PPG system according to examples of the disclosure.

FIG. 13B illustrates an exemplary process illustrating operation of a PPG system including a light emitter-light sensor set for motion detection according to examples of the disclosure.

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FIG. 13C illustrates an exemplary process illustrating operation of a PPG system including an accelerometer for motion detection according to examples of the disclosure.

FIG. 13D illustrates an exemplary process illustrating operation of a PPG system according to examples of the disclosure.

FIG. 14 illustrates an exemplary block diagram of a computing system comprising light emitters and light sensors for measuring a signal associated with a user's physiological state according to examples of the disclosure.

FIG. 15 illustrates an exemplary configuration in which an electronic device is connected to a host according to examples of the disclosure.

FIG. 16A illustrates a perspective view of an underside or back surface of a wearable device according to examples of the disclosure.

FIG. 16B illustrates a schematic side view of the back surface of FIG. 16A in contact with the skin surface of an individual.

FIG. 17A illustrates a perspective view of another variation of an underside or back surface of a wearable device according to examples of the disclosure.

FIG. 17B illustrates a schematic side view of the back surface of FIG. 17A in contact with the skin surface of an individual.

FIGS. 18A and 18B illustrate perspective views of other variations of an underside or back surface of a wearable device according to examples of the disclosure.

FIG. 18C illustrates a schematic side view of the back surface of FIG. 18A in contact with the skin surface of an individual.

FIG. 19A illustrates a perspective view of another variation of an underside or back surface of a wearable device according to examples of the disclosure.

FIG. 19B illustrates a schematic side view of the back surface of FIG. 19A in contact with the skin surface of an individual.

FIG. 20 illustrates a cross-sectional view of one variation of a protrusion.

FIG. 21A illustrates a cross-sectional view of one variation of a device comprising a protrusion and a Fresnel lens.

FIG. 21B illustrates a cross-sectional view of another variation of a device comprising a protrusion and a Fresnel lens.

FIG. 22A illustrates a cross-sectional view of one variation of a protrusion comprising an isolation or optical barrier.

FIG. 22B illustrates a cross-sectional view of one variation of a device comprising an isolation or an optical barrier, and a Fresnel lens disposed between the protrusion and the light emitter and light sensor.

FIG. 22C illustrates a cross-sectional view taken across line 22C-22C of one variation of a wearable device (e.g., the device depicted in FIG. 22D) comprising an isolation or an optical barrier and a Fresnel lens disposed between the protrusion and a plurality of light emitters and light sensor.

FIG. 22D illustrates a top view of the underside of a wearable device comprising one variation of a Fresnel lens.

FIG. 22E illustrates a top view of the underside of a device comprising another variation of a Fresnel lens.

FIGS. 23A-23C illustrate cross-sectional views of exemplary configurations of light emitters for co-localizing the noise reference and PPG channels according to examples of the disclosure.

## DETAILED DESCRIPTION

In the following description of examples, reference is made to the accompanying drawings in which it is shown by

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way of illustration specific examples that can be practiced. It is to be understood that other examples can be used and structural changes can be made without departing from the scope of the various examples.

This relates to systems and methods for determining one or more of a user's physiological signals. The one or more of the user's physiological signals can be determined by measuring pulsatile blood volume changes. Motion artifacts included in the signals can be canceled or reduced by measuring non-pulsatile blood volume changes and adjusting the signal to account for the non-pulsatile blood information. Deeper tissue of a user can be more susceptible to motion artifacts due to, for example, muscle movement, tendon movement, non-pulsatile blood movement, or a combination thereof. The effect of the motion artifacts can be less pronounced in the superficial layers of the user due to absence of the muscles and tendons. In some examples, non-pulsatile blood volume changes can be measured using at least one set of light emitter-light sensor. The light emitter can be located in close proximity (e.g., less than or equal to 1 mm away) to the light sensor to limit the depth within the tissue that is measured. Light can be emitted at one or more wavelengths (e.g., greater than 600 nm) less sensitive to oxy-hemoglobin, which can reduce the interaction of light to venous blood volume changes. In some examples, the systems can further include an accelerometer configured to measure the user's acceleration, and the acceleration signal can be additionally be used for compensating of motion artifacts.

Representative applications of methods and apparatus according to examples of the present disclosure are described in this section. These examples are being provided solely to add context and aid in the understanding of the described examples. It will thus be apparent to one skilled in the art that the described examples may be practiced without some or all of the specific details. In other instances, well-known process steps have been described in detail in order to avoid unnecessarily obscuring the described examples. Other applications are possible, such that the following examples should not be taken as limiting.

FIGS. 1A-1C illustrate systems in which examples of the disclosure can be implemented. FIG. 1A illustrates an exemplary mobile telephone 136 that can include a touch screen 124. FIG. 1B illustrates an exemplary media player 140 that can include a touch screen 126. FIG. 1C illustrates an exemplary wearable device 144 that can include a touch screen 128 and can be attached to a user using a strap 146. The systems of FIGS. 1A-1C can utilize the reconfigurable apertures and methods for detecting a PPG signal as will be disclosed.

FIG. 2A illustrates a top view and FIG. 2B illustrates a cross-sectional view of an exemplary electronic device including light sensors and light emitters for measuring a user's physiological signal according to examples of the disclosure. The top view in FIG. 2A can be viewed as the underside of wearable device 144 of FIG. 1C, for example. Device 200 can include light sensor 204, light sensor 214, light emitter 206, and light emitter 216. Light sensor 204 can be optically coupled to light emitter 206. Light sensor 214 can be optically coupled to light emitter 216. Device 200 can be situated such that light sensor 204, light sensor 214, light emitter 206, and light emitter 208 are proximate to a skin 220 of a user. For example, device 200 can be held in a user's hand or strapped to a user's wrist, among other possibilities.

Light emitter 206 can be configured to emit light (e.g., light 222). A portion of the one or more light paths can be

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absorbed by one or more blood vessels 242, and a portion of the one or more light paths can reflect back to be detected by a light sensor. For example, as illustrated in FIG. 2B, a portion of light 222 (emitted from light emitter 206) can be absorbed by blood vessel 242, and a portion of light (e.g., light 223) can reflect back for detection by light sensor 204. Light emitter 206 can also be configured to emit light, and a portion of the light can reflect back for detection by light sensor 214. Similarly, light emitter 216 can be configured to emit light towards light sensor 204 and light sensor 214.

Signal 250 can include the measured total signal (i.e., sum of the measured modulated light and unmodulated light) detected by the light sensor (e.g., light sensor 204). In some examples, the device or system can include an accelerometer 202. Accelerometer 202 can be any type of sensor capable of measuring acceleration. Signal 255 can include the measured acceleration signal detected by accelerometer 202. Device 200 can include a processor or controller 209 configured to determine the user's physiological signal from signal 250 and signal 255. The user's physiological signal can be determined using any number of algorithms or simple mathematical functions including, but not limited to, subtracting, multiplying, and/or scaling.

In some examples, the capabilities of the accelerometer included in the PPG system may be limited to measuring gross motion (e.g., the user waving his or her hand) and may not be capable of measuring anatomical motion (e.g., the user clenching his or her fist). In some examples, the capabilities of the accelerometer can be limited to periodic motion artifacts. As a result, signal 250 can include distortion from the anatomical motion, and the system may erroneously include the distortions in its determination of the user's physiological signal (due to the inability to distinguish anatomical motion). Examples of anatomical motion can include surface motion or motion induced by blood re-distribution (e.g., increases or decreases in venous blood caused by user motion). In some examples, the system can be capable of measuring solely non-pulsatile blood volume changes—where a system relying entirely on an accelerometer for noise correction may not be capable of measuring non-pulsatile blood volume changes. In some examples, the system can be capable of measuring non-periodic motion artifacts. By measuring the modulation of the optical signal from non-pulsatile blood volume changes, motion artifacts can be accurately determined.

FIG. 3A illustrates a top view and FIG. 3B illustrates a cross-sectional view of an exemplary electronic device including light sensors and light emitters for measuring a user's physiological signal according to examples of the disclosure. Device 300 can include light emitter 306, light emitter 308, light emitter 316, light emitter 318, light sensor 304, and light sensor 314. Each light emitter can be optically coupled to each light sensor. For example, light emitter 306 can be optically coupled to both light sensor 304 and light sensor 314. Similarly, light emitter 316 can be optically coupled to both light sensor 304 and light sensor 314. Device 300 can be situated such that light sensor 304, light sensor 314, light emitter 306, light emitter 308, light emitter 316, and light emitter 318 are proximate to a skin 320 of a user. For example, device 300 can be held in the user's hand or strapped to the user's wrist, among other possibilities.

Light emitter 306 can be configured to emit light and generate one or more light paths detected by light sensor 304 and one or more light paths detected by light sensor 314. Light emitter 308 can also be configured to emit light and generate one or more light paths detected by light sensor 304 and one or more light paths detected by light sensor 314.

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Light emitter 316 can be configured to emit light and generate one or more light paths detected by light sensor 304 and one or more light paths detected by light sensor 314. Light emitter 318 can also be configured to emit light and generate one or more light paths detected by light sensor 304 and one or more light paths detected by light sensor 314.

Device 300 can include a controller 309 configured to utilize the signal(s) from one or more lights paths to correct the signal(s) from one or more other lights paths to determine the user's physiological signal. The correction can be performed to cancel out any noise due to, for example, the user's motion, motions from within the user's body (e.g., tendon motion and/or muscle motion), tilt and/or pull of the device, ambient light variations, or any combination thereof. Device 300 can be in close proximity to skin 320 of a user and configured such that light emitter 306, light emitter 308, light emitter 316, and light emitter 318 can emit light towards skin 320. A plurality of blood vessels can be located in skin 320. For example, as illustrated in the FIG. 3B, one or more blood vessels 342 can be located in one or more deeper layers, such as layer 346 (e.g., the subcutaneous tissue), in skin 320, and one or more arterioles 334 can be located in one or more shallower layers, such as layer 345 (e.g., the dermis tissue), in skin 320.

In some examples, light emitter 306 and light sensor 304 can be located such that light path 322 emitted by light emitter 306 can reach layer 346 (e.g., a layer including the subcutaneous tissue), which can be located deeper within skin 320 than layer 345 (e.g., a layer including dermis tissue). A portion of light 322 can be absorbed by one or more arterioles 334 and/or one or more blood vessels 342 located in layer 345 and layer 346, and a portion of light (i.e., light 323) can reflect back for detection by light sensor 304. Light sensor 304 can generate signal 350, which can be measured by controller 309. Light emitter 308 and light sensor 304 can be located such that light 324 emitted by light emitter 308 can be sensitive to arterial blood volume changes. A portion of light 324 can be absorbed by one or more arterioles 334 in layer 345, and a portion of light (i.e., light 325) can reflect back for detection by light sensor 304. Light sensor 304 can generate signal 355, which can be measured by controller 309.

Signal 350 can include measured total signal (i.e., sum of the measured modulated light and unmodulated light) representative of light 323 detected by light sensor 304. Signal 355 can be the measured signal representative of light 325 detected by light sensor 304. In some examples, the user's motion (and/or motions from within the user's body (e.g., tendon motion and/or muscle motion)), can distort light 323 and light 325, which can change both signal 350 and signal 355. Since light 324 can be sensitive to arterial blood volume changes, signal 355 can include both pulsatile blood information and motion artifacts (e.g., non-pulsatile blood information from either deep or shallow tissue structures). Controller 309 can utilize an algorithm or simple mathematical functions can be applied to signal 350 and signal 355 to determine the user's physiological signal (e.g., signal 360 illustrated in FIG. 3C). However, given that light 324 can be absorbed by one or more arterioles 334, a portion of signal 355 may include pulsatile blood information. Thus, signal 355 may not be entirely representative of motion artifacts.

In some examples, the signals from one or more sets of light emitter-light sensor can be utilized to perform other functions. For example, light emitter 308 and/or light emitter 316 can be configured for monitoring off-wrist detection. In some examples, light emitter 308 and/or light emitter 316 can be configured to measure the background user's physi-

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ological signal (e.g., heart rate) when the user may not be moving. The system can monitor the user's motion through an accelerometer to determine whether the user is moving.

FIG. 3C illustrates exemplary circuitry coupled to the light sensors and light emitters and utilized for estimation of the user's physiological signals according to examples of the disclosure. FIG. 3D illustrates an exemplary corresponding process flow according to example of the disclosure. System 300 can include light emitter 306, light emitter 308, light emitter 316, and light emitter 318 configured to emit light (e.g., light 322 and light 324) towards the user (step 372 of process 370). A portion of the emitted light can reflect back (e.g., light 323 and light 325) towards one or more light sensors (e.g., light sensor 304 and/or light sensor 314). Light sensor 304 and light sensor 314 can be configured to generate a plurality of signals 350 in response to the detected reflected light (e.g., light 323 or light 325) (step 374 of process 370). System 300 can include a plurality of filters 310. Each filter 310 can be configured to receive a plurality of signals 350 from a light sensor and can filter the signals (step 376 of process 370). Plurality of filters 310 can be any type of filter capable of selection based on one or more properties, such as a bandpass filter capable of selecting a range of frequencies. In some examples, plurality of filters 310 can be adaptive filters. Each of the plurality of signals 350 generated from the light sensor can represent detected reflected light from different light emitters. For example, filter 310a can receive signal 350a and signal 350b. Signal 350a and signal 350b can be generated from light sensor 304, where signal 350a can represent detected reflected light from light emitter 306, and signal 350b can represent detected reflected light from light emitter 308. That is, signal 350a can represent signal information, and signal 350b can represent a noise reference channel. In some examples, for a given filter 310, the signal from one light emitter can represent the user's physiological signal and noise, and the signal from the other light emitter can represent noise. For example, light emitter 306 can be configured to emit light in the wavelength range of 495-570 nm, and signal 350a can represent the pulsatile blood volume changes of the user. Light emitter 308 can be configured to emit light in the wavelength range of 750-1400 nm, and the reflected light (e.g., light 325) can represent noise.

Plurality of signals 352 from plurality of filters 310 can be input into controller 309. System 300 can also include accelerometer 302. Accelerometer 302 can be configured to generate signal 355 indicative of the user's acceleration or gross motion (step 378 of process 370). Controller 309 can receive plurality of signals 352 from plurality of filters 310 and signal 355 from accelerometer 302 to determine the user's physiological signal 360 using one or more algorithms or simple mathematical functions (step 380 of process 370).

FIG. 4A illustrates a top view and FIG. 4B illustrates a cross-sectional view of an exemplary electronic device including a dedicated light sensor and light emitter set for noise correction utilized in measuring a user's physiological signal according to examples of the disclosure. Device 400 can include light emitter 405, light emitter 406, light emitter 415, and light emitter 416. Device 400 can further include light sensor 404, light sensor 407, light sensor 414, and light sensor 417. Light emitter 406 can be configured to emit light towards light sensor 404 and light sensor 414. Light emitter 405 can be configured to emit light towards light sensor 407. Light emitter 416 can be configured to emit light towards light sensor 404 and light sensor 414. Light emitter 415 can be configured to emit light towards light sensor 414. In some

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examples, light emitter 406 and light emitter 416 can be located such that the path lengths to light sensor 404 are different from the path lengths to light sensor 414.

Device 400 can be configured such that one or more light emitters are optically coupled to one or more light sensors, where the one or more light emitters are located in a different cavity than the one or more light sensors. For example, light emitter 406 can be optically coupled to light sensor 404, where light emitter 406 can be located in cavity 466 and light sensor 404 can be located in cavity 464. In some examples, each cavity can be associated with a different aperture 401 (where light exits and enters device 400) and/or window. Device 400 can also be configured such that one or more light emitters can be optically coupled to one or more light sensors, where the one or more light emitters can be located in the same cavity as the one or more light sensors. For example, light emitter 405 can be optically coupled to light sensor 407, where both can be located in cavity 466. In some examples, the cavities included in device 400 can be separated by isolation 419.

In some examples, one or more sets of light emitter-light sensor located in different cavities can be configured to measure pulsatile blood volume changes. In some examples, one or more light emitter-light sensor sets located in the same cavity can be configured to measure non-pulsatile blood volume changes (from shallow tissues structures, deep tissue structures, or both) and/or serve as a noise reference channel. For example, the set comprising light emitter 406 and light sensor 404 can be configured to be sensitive to pulsatile blood volume changes. Light emitter 406 can emit light 422. Light 422 can be incident on blood vessel 442 located in layer 446, and a portion of the light can reflect back as light 423. Light sensor 404 can measure light 423 and can generate signal 450, where signal 450 can include both pulsatile blood volume changes and noise information. The set comprising light emitter 405 and light sensor 407 can be less sensitive to arterial blood volume changes (than the set comprising light emitter 406 and light sensor 404) and can be configured to generate a signal indicative of the non-pulsatile blood changes. Light emitter 405 can be located in close proximity (e.g., less than or equal to 1 mm away) to light sensor 407. Light emitter 405 can emit light 426. A portion of light 426 can penetrate through skin 420, and a portion of the light can reflect back as light 427. Light sensor 407 can detect light 427 and can generate signal 455, where signal 455 can include noise information. The spacing between light emitter 405 and light sensor 407 can prevent light 426 from reaching one or more deep layers (e.g., layer 446). Deeper tissue of a user can be more susceptible to motion artifacts due to, for example, muscle movement, tendon movement, non-pulsatile blood movement, or a combination thereof. The effect of the motion artifacts can be less pronounced in the superficial layers of the user due to absence of the muscles and tendons. In some examples, light 427 can be emitted at one or more wavelengths (e.g., greater than 600 nm) less sensitive to oxy-hemoglobin, which can reduce the interaction of light to venous blood volume changes. Controller 409 can receive signal 450 and signal 455 and can apply one or more algorithms to determine the user's physiological signal. Additional light paths formed between light sensors and light emitters can be included in examples of the disclosure and are not shown in the figure for clarity purposes.

FIG. 4C illustrates a cross-sectional view of an exemplary electronic device including a light sensor optically coupled to a light emitter in the same cavity, but divided by an isolation according to examples of the disclosure. Device

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400 can include isolation 421 located between a light emitter-light sensor set included in the same cavity (e.g., cavity 466). Isolation 421 can be any material configured to optically isolate light emitter 405 from light sensor 407. Exemplary materials for isolation can include, but are not limited to, carbon. In some examples, window 403 can be configured to reject one or more angles of light. In some examples, the rejected angles can include high angles (e.g., greater than 50 degrees) such that reflections from the surface of skin 420 and/or from the surface of window 403. In some examples, window 403 can be a Fresnel lens.

In some examples, device 400 can be located in close proximity (e.g., less than 5 mm away) or in contact with skin 420 to help prevent light 427 from including any light that has merely reflected off the surface of skin 420 and/or the surface of device 400. In this manner, penetration of light 426 can be better controlled. The close spacing of light emitter 405 and light sensor 407 can prevent the reflected light 427 from including non-pulsatile blood information. Isolation 421 and/or close proximity of the surface device 400 to skin 420 can prevent reflected light 427 from including reflections off the surface of skin 420 and/or surface of device 400. In some examples, the light sensor's numerical aperture can be configured to prevent light 427 from including any light that has merely reflected off the surface of skin 420 and/or the surface of device 400. Although FIG. 4C illustrates isolation 421 ending at the inner surface (i.e., surface closest to light emitter 405 and light sensor 407) of window 403, examples can include isolation 421 ending at the outer surface (i.e., surface furthest from light emitter 405 and light sensor 407) of window 403 as illustrated in FIG. 4D. In some examples, isolation 421 can comprise a plurality of materials, where the material(s) within the cavity can be different from the material(s) within the window. In some examples, isolation 421 can be continuous and/or the same material along the cavity and the window.

FIG. 5A illustrates a top view and FIG. 5B illustrates a cross-sectional view of an exemplary electronic device including at least one separate light sensor and light emitter set for noise correction utilized in measuring a user's physiological signal according to examples of the disclosure. Device 500 can include light emitter 505, light emitter 506, light emitter 515, and light emitter 516. Device 500 can also include light sensor 504, light sensor 507, light sensor 514, and light sensor 517. Light emitter 505 can be configured to emit light towards light sensor 504 and light sensor 514. Light emitter 506 can be configured to emit light towards light sensor 507. Light emitter 515 can be configured to emit light towards light sensor 504 and light sensor 514. Light emitter 516 can be configured to emit light towards light sensor 517. In some examples, light emitter 505 and light emitter 515 can be located closer to the center of device 500, whereas light emitter 506, light sensor 507, light emitter 516, and light emitter 517 can be located closer to the outer edges of device 500. In some examples, light emitter 505 and light emitter 515 can be located such that the path lengths to light sensor 504 are the same as the path lengths to light sensor 514.

Device 500 can be configured such that one or more light emitters are optically coupled to one or more light sensors, where the one or more light emitters are located in a different cavity than the one or more light sensors. For example, light emitter 505 can be optically coupled to light sensor 504, where light emitter 505 can be located in cavity 566 and light sensor 504 can be located in a cavity 564. In some examples, each cavity can be associated with a different aperture (where light exits and enters the device) and/or

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window. Device 500 can also be configured such that one or more light emitters are optically coupled to one or more light sensors, where the one or more light emitters are located in the same cavity as the one or more light sensors. For example, light emitter 506 can be optically coupled to light sensor 507, where both can be located in cavity 566. In some examples, the cavities included in device 500 can be separated by isolation 519.

Similarly, light emitter 515 can be optically coupled to light sensor 504 and light sensor 514, where each light sensor can be located in a different cavity than light emitter 515. Light emitter 516 can be optically coupled to light sensor 517, where each can be located in the same cavity.

In some examples, one or more light emitter-light sensor sets located in different cavities can be configured to measure pulsatile blood volume changes. In some examples, one or more light emitter-light sensor sets located in the same cavity can be configured to measure non-pulsatile blood volume changes and/or serve as a noise reference channel. The set comprising light emitter 515 and light sensor 504 and/or the set comprising light emitter 515 and light sensor 514 can be configured to measure pulsatile blood changes. The signals generated from these sets can include both pulsatile blood volume changes and noise information. The set comprising light emitter 516 and light sensor 517 can be configured to measure non-pulsatile blood changes. Light emitter 516 can be located in close proximity (e.g., less than or equal to 1 mm away) from light sensor 517. The spacing between light emitter 516 and light sensor 517 can prevent the emitted light from reaching one or more arterioles 534 and/or one or more blood vessels 542, and hence, the associated signal can include little-to-no pulsatile blood information. Controller 509 can receive one or more signals that include pulsatile blood volume changes (e.g., signals, such as signal 550, from light sensor 504) and one or more signals that includes little-to-no pulsatile blood information (e.g., signals, such as signal 555, from light sensor 507) and can apply one or more algorithms to determine the user's physiological signal. Additional light paths formed between light sensors and light emitters can be included in examples of the disclosure and are not shown in the figure for clarity purposes.

FIG. 5C illustrates a cross-sectional view of an exemplary electronic device including a light sensor optically coupled to a light emitter in the same cavity, but divided by an isolation according to examples of the disclosure. Device 500 can further include isolation 521 located between a light emitter-light sensor set included in the same cavity. Isolation 521 can be any material configured to optically isolate light emitter 506 from light sensor 507. Exemplary materials for isolation can include, but are not limited to, carbon. In some examples, isolation 521 can be configured to focus and/or collimate light 526 such that light 526 can exit cavity 566 and/or aperture 501. In some examples, device 500 can be located in close proximity (e.g., less than 5 mm away) or in contact with skin 520 to help prevent light 527 from including any light that has merely reflected off the surface of skin 520 and/or surface of device 500. In this manner, the penetration of light 526 can be controlled. The close spacing of light emitter 506 and light sensor 507 can prevent reflected light 527 from including non-pulsatile blood information. Isolation 521 and/or close proximity of device 500 to skin 520 can prevent reflected light 527 from including reflections from the surface of skin 520 and/or surface of device 500. Although FIG. 5C illustrates isolation 521 ending at the inner surface (i.e., surface closest to light emitter 505 and light sensor 507) of window 503, examples

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can include isolation 521 ending at the outer surface (i.e., surface furthest from light emitter 505 and light sensor 507) of window 503 (not shown). In some examples, isolation can comprise a plurality of materials, where the material(s) within the cavity can be different from the material(s) within the window. In some examples, isolation can be continuous and/or the same material along the cavity and the window.

In some examples, light sensor 507 can be coupled to a passband filter and/or can be configured to detect only those wavelengths of light emitted by light emitter 506. In this manner, light sensor 507 may not detect light emitted from light emitter 505. In some examples, light sensor 507 can be configured to detect wavelengths of light emitted by light emitter 506 and wavelengths of light emitted by light emitter 505. In some examples, the different wavelengths of light can provide different types of information. For example, light emitter 506 can emit red light (or light within 700-750 nm), and light emitter 505 can emit green light (or light within 495-570 nm). Light sensor 507 can be configured to detect both red light and green light, where detected red light can be used for determining motion artifacts, and detected green light can be used for off-wrist detection. Moreover, light sensor 504 can detect light emitted from light emitter 505 that can pass through the multiple layers of skin 520 and pulsatile blood flow (i.e., one or more blood vessels 542 and/or one or more arterioles 534).

Although FIGS. 4A and 5A illustrate four light emitters, examples of the disclosure can include any number of light emitters. In addition, examples of the disclosure can include one or more common light sensors that can be used for detecting signals including pulsatile blood information and signals including non-pulsatile blood information.

FIG. 6A illustrates a top view and FIG. 6B illustrates a cross-sectional view of an exemplary electronic device including a light sensor optically coupled to a common light emitter used for noise correction utilized in measuring a user's physiological signal according to examples of the disclosure. Device 600 can include light emitter 606, light emitter 608, light emitter 616, and light emitter 618. Device 600 can also include light sensor 604 and light sensor 614. Light emitter 606 can be configured to emit light towards light sensor 604 and light sensor 614. Light emitter 608 can also be configured to emit light towards light sensor 604 and light sensor 614. Light emitter 616 can be configured to emit light towards light sensor 604 and light sensor 614. Light emitter 618 can also be configured to emit light towards light sensor 604 and light sensor 614. In some examples, light emitter 606 and light emitter 616 can be located such that the path lengths to light sensor 604 and to light sensor 614 are the same. In some examples, light emitter 608 and light emitter 618 can be located such that the path lengths to light sensor 604 and to light sensor 614 are the same. In some examples, light emitter 606 and light emitter 616 can be located closer to the center of device 600 than light emitter 608 and light emitter 618.

Device 600 can further include light emitter 605 and light emitter 615. Light emitter 605 can be located in close proximity to and can be configured to emit light towards light sensor 604. Light emitter 615 can be located in close proximity to and can be configured to emit light towards light sensor 614. Light sensor 604 can be configured as a common light sensor that can detect light reflected from one or more blood vessels 642 and/or one or more arterioles 634, where pulsatile blood volume changes can be determined based on the detected reflect light. For example, pulsatile blood volume changes can affect light 623 and light 627. Light 623 can include information from layer 644 and layer

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645, and light 627 can include information from layer 644, layer 645, and layer 646. Light sensor 604 can also detect light reflected from light 625, which can be sensitive to venous blood (non-pulsatile blood) volume changes due to the light emitter being located in close proximity (e.g., less than or equal to 1 mm away) to the light sensor and/or emitting light at specific wavelengths (e.g., greater than 600 nm), for example.

In some examples, light emitter 606 and light emitter 608 can be located in the same cavity 666, and light emitter 616 and light emitter 618 can be located in the same cavity. In each cavity, at least one light emitter can be configured to emit light at a wavelength different from another light emitter. Different types of information can be extracted from the different wavelengths of light. For example, light emitter 606 can be configured to emit light 622. Light 622 can travel through one or more layers of skin 620, and a portion of the light can reflect back as light 623 to be detected by light sensor 604. Light emitter 608 can be configured to emit light 626. Light 626 can travel through one or more layers of skin 620, and a portion of the light can reflect back as light 627 to be detected by light sensor 604. The separation distance between light emitter 606 and light sensor 604 can be shorter than the separation distance between light emitter 608 and light sensor 604. Additionally or alternatively, light 622 can have a shorter wavelength than the wavelength of light 626. In some examples, the shorter separation distance and/or shorter wavelength can lead to light 622 and light 623 having a shorter path length than light 626 and light 627. As a result, light 622/623 may not penetrate as deep in skin 620 as light 626/627. Light sensor 604 can generate a plurality of signals, including signal 652 representative of light 623, signal 650 representative of light 627, and signal 655 representative of light 625. Although FIG. 6A illustrates light emitter 605 and light emitter 615 located in a center of light sensor 604 and light sensor 614, respectively, examples of the disclosure can include light emitter 605 and light emitter 615 located in other locations (e.g., to one side) with respect to light sensor 604 and light sensor 614, respectively.

FIG. 6C illustrates a cross-sectional view of an exemplary electronic device including a light sensor optically coupled to a common light emitter used for noise correction utilized in measuring a user's physiological signal according to examples of the disclosure. Device 600 can include isolation 617 located between light emitter 605 and light sensor 604. Device 600 can also include isolation 621 located between light emitter 608 and light emitter 606. In some examples, isolation 621 can be configured to prevent light mixing between light emitted by light emitter 606 and light emitted by light emitter 608. Isolation 617 and isolation 621 can be any material configured for optical isolation. Exemplary materials for isolation can include, but are not limited to, carbon.

In some examples, isolation 617 can be configured to focus and/or collimate light 624 such that light 624 can exit cavity 664. In some examples, device 600 can be located in close proximity (e.g., less than 5 mm away) or in contact with skin 420 to help prevent light 625 from including any light that has merely reflected off the surface of skin 620 and/or the surface of device 600. In this manner, the penetration of light 624 can be controlled. The close spacing of light emitter 605 and light sensor 604 can prevent reflected light 625 from including pulsatile blood information. Isolation 617 and/or close proximity to the surface of device 600 to skin 620 can prevent reflected light 625 from including reflections from the surface of skin 620 and/or surface of device 600. Additionally or alternatively, isolation 621 can

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be configured to focus and/or collimate light 622 and/or light 626 such that light 622 and/or light 626 can exit cavity 666. Penetration of light 622 and light 626 can be controlled such that reflected light 623 and reflected light 627 can include pulsatile blood information.

Although FIG. 6C illustrates isolation 617 and isolation 621 ending at the inner surface (i.e., surface closest to light emitter 605, light sensor 604, light emitter 606, and light emitter 608) of windows 603, examples of the disclosure can include isolation 617 and/or isolation 621 ending at the outer surface (i.e., surface furthest from light emitter 605, light sensor 604, light emitter 606, and light emitter 608) of windows 603 (not shown). In some examples, isolation can comprise a plurality of materials, where the material(s) within the cavity can be different from the material(s) within window. In some examples, isolation can be continuous and/or the same material along the cavity and the window.

FIG. 6D illustrates a cross-sectional view of an exemplary electronic device including angled isolation according to examples of the disclosure. Device 600 can include isolation 617 located between light sensor 604 and light emitter 605. Device 600 can also include isolation 621 located between light emitter 606 and light emitter 608. Isolation 617 and/or isolation 621 can be angled or non-orthogonal to windows 603, which can focus and/or collimate light 624 and light 626. In some examples, isolation 617 and isolation 621 can steer light 624 and light 626, respectively, more than isolation that is orthogonal to the windows (e.g., isolation 421 illustrated in FIG. 4D). In some examples, one or more of isolation 617 and isolation 621 can be angled towards (i.e., spacing between isolations can be located closer to the windows 603) isolation 619.

FIG. 7A illustrates a top view and FIG. 7B illustrates a cross-sectional view of an exemplary electronic device including at least two different cavities, each cavity can include at least one light sensor and a plurality of light emitters according to examples of the disclosure. Device 700 can include cavity 743 and cavity 746. Cavity 743 can include light emitter 705, light emitter 706, light emitter 708, and light sensor 704. Cavity 746 can include light emitter 715, light emitter 716, light emitter 718, and light sensor 714. Device 700 can be configured such that each light sensor can be surrounded by light emitters and/or the edge of device 700. For example, light sensor 704 can be located between a first column of light emitters (e.g., column formed by light emitter 705, light emitter 706, and light emitter 708) and a second column of light emitters (e.g., column formed by light emitter 715, light emitter 716, and light emitter 718).

Device 700 can be configured such that in each cavity, at least one light emitter can be optically coupled to a light sensor in the cavity, and at least one light emitter can be optically coupled to a light sensor in another cavity. A plurality of overlapping light paths can be formed by the plurality of light emitted from light emitters that can be optically coupled to a light sensor in another cavity. In this manner, multiple light paths can "cross" over each other, which can increase the locations on skin 720 that can be sampled.

Light emitter 705 can be configured to emit light 722. Light 722 can enter skin 720, and a portion can reflect back as light 723 to be detected by light sensor 714, which can be a light sensor optically coupled to a light emitter in a different cavity. Light emitter 705 can be located relative to light sensor 714 such that one or more areas of skin 720 located along the optical path of light 722/723 can be measured. The measurement can include light 722 and/or

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light 723 undergoing optical changes due to pulsatile blood volume changes from, for example, one or more blood vessels 742 and/or one or more arterioles 734.

Light emitter 706 can be configured to emit light 724. Light 724 can enter skin 720, and a portion can reflect back as light 725 to be detected by light sensor 704, which can be a light sensor optically coupled to a light emitter in the same cavity. Light emitter 706 can be located in close proximity to light sensor 704 such that the penetration of light 724 can be limited to shallower layers (e.g., layer 744 and/or layer 745). In some examples, light 724 can include specific wavelengths (e.g., greater than 600 nm), thereby limiting light 724/725 to be sensitive to venous blood (non-pulsatile blood) volume changes.

Light emitter 715 can be configured to emit light 726. Light 726 can enter skin 720, and a portion can reflect back as light 727 to be detected by light sensor 704, which can be a light sensor optically coupled to a light emitter in a different cavity. Light emitter 715 can be located relative to light sensor 704 such that one or more areas of skin 720 located along the optical path of light 726/727 can be measured. The measurement can include light 726 and/or light 727 undergoing optical changes due to pulsatile blood volumes changes from, for example, one or more blood vessels 742 and/or one or more arterioles 734. In some examples, light emitter 715-light sensor 704 set can measure one or more areas of skin 720 different than the one or more areas of skin 720 measured by light emitter 705-light sensor 714 set. In some examples, one or more blood vessels 742 and/or one or more arterioles 734 measured by light 726/727 can be different from the one or more blood vessels 742 and/or one or more arterioles 734 measured by light 722/723. In some examples, the light path from light 722/723 can cross or intersect with the light path from light 726/light 727. The angle of intersection between the light paths can be adjusted based on the location of the corresponding optical components, which can then adjust the measurement profile of the one or more areas in skin 720.

Light emitter 716 can be configured to emit light 728. Light 728 can enter skin 720, and a portion can reflect back as light 729 to be detected by light sensor 714, which can be a light sensor optically coupled to a light emitter in the same cavity. Light emitter 716 can be located in close proximity (e.g., less than or equal to 1 mm away) to light sensor 714 such that the penetration of light 728 can be limited to shallower layers (e.g., layer 744 and/or layer 745). In some examples, light 728/729 can include specific wavelengths (e.g., greater than 600 nm), thereby limiting the sensitivity of light 728/729 to venous blood (non-pulsatile blood) volume changes. In some examples, the separation distance between light emitter 706 and light sensor 704 can be the same as the separation distance between light emitter 716 and light sensor 714. In some examples, the separation distance between light emitter 706 and light sensor 704 can be different from the separation distance between light emitter 716 and light sensor 714. In some examples, light 725 can include the same noise artifacts as light 729. In some examples, light 725 can include different noise artifacts than light 729. If the noise artifacts are different, then device 700 can utilize the difference in noise artifacts to determine whether the noise originates from multiple sources. For example, a difference in noise artifacts can be indicative of a tilt and/or pull experienced by one side of the device and not by the other side of the device. Additional light paths formed between light sensors and light emitters can be included in examples of the disclosure and are not shown in the figure for clarity purposes.

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FIG. 7C illustrates a cross-sectional view of an exemplary electronic device including at least two different cavities, each cavity including at least one light sensor and a plurality of light emitters divided by an isolation according to examples of the disclosure. To prevent light 725 and/or light 729 from including reflected light at the interfaces (e.g., at the surface of skin 720, at the surface of window 703, and/or at the surface of device 700), device 700 can include isolation 717 and/or isolation 721. In this manner, light 725 and/or light 729 can include information related to non-pulsatile blood and/or other noise artifacts (e.g., noise from a tilt and/or pull of the device or ambient light variations).

FIG. 8A illustrates a top view and FIG. 8B illustrates a cross-sectional view of an exemplary electronic device including at least two different cavities, each cavity including at least one light sensor and a plurality of light emitters according to examples of the disclosure. Device 800 can include cavity 843 and cavity 846. Cavity 843 can include light emitter 805, light emitter 806, light emitter 808, and light sensor 804. Cavity 846 can include light emitter 815, light emitter 816, light emitter 818, and light sensor 814. Device 800 can be configured such that light sensor 804 and light sensor 814 are adjacent optical components. In some examples, light sensor 804 and light sensor 814 can be symmetrically (horizontally) placed on device 800 with respect to its center. Light emitter 805, light emitter 806, and light emitter 808 can be located on one side of device 800, and light emitter 815, light emitter 816, and light emitter 818 can be located on the opposite side of device 800.

Device 800 can be configured such that in each cavity, at least one light emitter can be optically coupled to a light sensor in the cavity, and at least one light emitter can be optically coupled to a light sensor in another cavity. A plurality of overlapping light paths can be formed by the plurality of light emitted from light emitters that can be optically coupled to a light sensor in another cavity. In this manner, multiple light paths can "cross" over each other, which can increase the locations within skin 820 that device 800 can sample.

Light emitter 805 can be configured to emit light 822. Light 822 can enter skin 820, and a portion can reflect back as light 823 to be detected by light sensor 814, which can be a light sensor optically coupled to a light emitter in a different cavity. Light emitter 805 can be located relative to light sensor 814 such that one or more areas of skin 820 located along the optical path of light 822/823 can be measured. The measurement can include light 822 and/or light 823 undergoing optical changes due to pulsatile blood volume changes from, for example, one or more blood vessels 842 and/or one or more arterioles 834.

Light emitter 806 can be configured to emit light 824. Light 824 can enter skin 820, and a portion can reflect back as light 825 to be detected by light sensor 804, which can be a light sensor optically coupled to a light emitter in the same cavity. Light emitter 806 can be located in close proximity (e.g., less than or equal to 1 mm away) to light sensor 804 such that the penetration of light 824 can be limited to shallower layers (e.g., layer 844 and/or layer 845). Light 824/825 can include specific wavelengths (e.g., greater than 600 nm), thereby limiting the sensitivity of light 824/825 to venous blood (non-pulsatile blood) volume changes.

Light emitter 815 can be configured to emit light 826. Light 826 can enter skin 820, and a portion can reflect back as light 827 to be detected by light sensor 804, which can be a light sensor optically coupled to a light emitter in a different cavity. Light emitter 816 can be located relative to light sensor 804 such that one or more areas of skin 820



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located along the optical path of light **826/827** can be measured. The measurement can include light **826** and/or light **827** undergoing optical changes due to pulsatile blood volumes changes from, for example, one or more blood vessels **842** and/or one or more arterioles **834**. In some examples, light emitter **815**-light sensor **804** set can measure one or more areas of skin **820** different than the one or more areas of skin **820** measured by light emitter **805**-light sensor **814** set. In some examples, one or more blood vessels **842** and/or one or more arterioles **834** measured by light **826/827** can be different than the one or more blood vessels **842** and/or one or more arterioles **834** measured by light **822/823**. In some examples, the light path from light **822/823** can cross or intersect with the light path from light **826/827**. The angle of intersection between the light paths can be adjusted based on the location of the corresponding optical components, which can then adjust the measurement profile of the one or more areas in skin **820**. By locating light emitters (e.g., light emitter **805**, light emitter **806**, and light emitter **808**) on one side of device **800** and locating light emitters (e.g., light emitter **815**, light emitter **816**, and light emitter **818**) on another side of device **800**, the light paths can have a greater separation distance relative to one another (compared to, for example, the light paths illustrated in FIG. 7B). Different characteristics (e.g., size, shape, and/or location) of the measurement areas on the skin **820** can be obtained.

Light emitter **816** can be configured to emit light **828**. Light **828** can enter skin **820**, and a portion can reflect back as light **829** to be detected by light sensor **814**, which can be a light sensor optically coupled to a light emitter in the same cavity. Light emitter **816** can be located in close proximity (e.g., less than or equal to 1 mm away) to light sensor **814** such that the penetration of light **828** can be limited to shallower layers (e.g., layer **844** and/or layer **845**). Light **828/829** can include specific wavelengths (e.g., greater than 600 nm), thereby limiting the sensitivity of light **828/829** to venous blood (non-pulsatile blood) volume changes. In some examples, the separation distance between light emitter **816** and light sensor **814** can be the same as the separation distance between light emitter **806** and light sensor **804**. In some examples, the separation distance between light emitter **816** and light sensor **814** can be different from the separation distance between light emitter **806** and light sensor **804**. In some examples, light **825** can include the same noise artifacts as light **829**. In some examples, light **825** can include different noise artifacts than light **829**. If the noise artifacts are different, then device **800** can utilize the difference in noise artifacts to determine whether the noise originates from multiple sources. For example, a difference in noise artifacts can be indicative of a tilt and/or pull experienced by one side of the device and not the other.

In some examples, the system can be configured with a plurality of sets of light emitter-light sensor, where the light emitters and light sensors have a common optical axis. For example, light emitter **806** can be configured to emit light towards light sensor **814**. Multiple light paths can exist. For example, one light path can be between light emitter **806** and light sensor **804**, and another light path can be between light emitter **806** and light sensor **814**. The light path between light emitter **806** and light sensor **804** can be utilized for noise correction, and the light path between light emitter **806** and light sensor **814** can be utilized for pulsatile blood information. Additional light paths formed between light sensors and light emitters can be included in examples of the disclosure and are not shown in the figure for clarity purposes.

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FIG. 8C illustrates a cross-sectional view of an exemplary electronic device including at least two different cavities, each cavity including at least one light sensor and a plurality of light emitters divided by an isolation according to examples of the disclosure. To prevent light **825** and/or light **829** from including reflected light at the interfaces (e.g., at the surface of skin **820**, at the surface of window **803**, at the surface of device **800**), device **800** can include isolation **817** and/or isolation **821**. In this manner, light **825** and/or light **829** can include non-pulsatile blood information. In some examples, light **825** and/or light **829** can exclude pulsatile blood information.

Although FIGS. 7A and 8A illustrate the light emitters arranged to form columns (relative to the long axis of device **700** and device **800**), examples of the disclosure can include the light emitters arranged to form rows. FIGS. 8D-8E illustrate top views of exemplary configurations for light emitters, light sensors, and isolation for electronic devices according to examples of the disclosure. As illustrated in FIG. 8D, light sensor **804** and light sensor **814** can be located on one side of device **800**, and the rows of light emitters (e.g., row formed by light emitter **805**, light emitter **806**, and light emitter **808** and row formed by light emitter **815**, light emitter **816**, and light emitter **818**) can be located on another side of device **800**. The light sensors and rows of light emitters can be separated by isolation **817** and isolation **821**. Additionally, cavity **843** can and cavity **846** can be separated by isolation **819**. The configuration can lead to one or more intersection light paths. Additional light paths formed between light sensors and light emitters can be included in examples of the disclosure and are not shown in the figure for clarity purposes.

As illustrated in FIG. 8E, light sensor **804** and one row of light emitters (e.g., row formed by light emitter **815**, light emitter **816**, and light emitter **818**) can be located on one side of device **800**. Additionally, light sensor **814** and another row of light emitters (e.g., row formed by light emitter **805**, light emitter **806**, and light emitter **808**) can be located on another side of device **800**. Each row of light emitters can be divided by isolation (e.g., isolation **817** or isolation **821**) from a light sensor. This configuration can lead to non-overlapping light paths as shown in the figure. Additional light paths formed between light sensors and light emitters can be included in examples of the disclosure and are not shown in the figure for clarity purposes.

Examples of the disclosure are not limited to rows of light emitters, but can include any configurations such as illustrated in FIG. 8F. For example, light emitter **805** and light emitter **806** can be located in a row different from light emitter **808**. Light emitter **808** can be located in the same column as light emitter **805** or light emitter **806** or can be located in a column different from light emitter **805** and light emitter **806**. Similarly, light emitter **815** and light emitter **816** can be located in a row different from light emitter **818**. Light emitter **818** can be located in the same column as light emitter **815**, or light emitter **816** or can be located in a column different from light emitter **815** and light emitter **818**. In some examples, the light emitters and light sensors can be symmetrically located (e.g., light sensor **804** can be located the same distance away from the center of the device as light sensor **814**) with respect to the center of device **800**. In some examples, the light emitters and light sensors can be asymmetrically located with respect to the center of device **800**. In some examples, the light sensors can be located closer to the edges of device **800** than the light emitters. In some examples, the light emitters can be located closer to the edges of device **800** than the light sensors. Additional

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light paths formed between light sensors and light emitters can be included in examples of the disclosure and are not shown in the figure for clarity purposes.

FIG. 9A illustrates exemplary oxy-hemoglobin and deoxy-hemoglobin absorption signals measured across a plurality of wavelengths according to examples of the disclosure. The spectrum can include a plurality of wavelength ranges, such as wavelength range 963, wavelength range 964, wavelength range 965, wavelength range 966, and wavelength range 967. Signal 950 can include the oxy-hemoglobin absorbance signal, and signal 955 can include the deoxy-hemoglobin absorbance signal. At one or more wavelengths (e.g., wavelength 961) in the spectrum, signal 950 and signal 955 can intersect. That is, signal 950 and signal 955 can have the same or similar absorbance values. A PPG system configured to measure the user's physiological signal at or within close proximity to these one or more wavelengths (e.g., wavelength 961 corresponding to an intersection of the signals) may not be capable of discerning whether the measured reflected light associated originates from oxy absorbance or de-oxy absorbance.

Examples of the disclosure can include a system capable of measuring both oxy-hemoglobin and deoxy-hemoglobin absorbance values in one or more wavelength ranges, where the oxy-hemoglobin and deoxy-hemoglobin absorbance signals are non-intersecting. In some examples, the system can be configured to measure at one or more wavelengths where the difference in absorbance values of the signals are greater than a pre-determined threshold (e.g., 10% difference). In some examples, the one or more measured wavelengths (e.g., wavelength 962) can correspond to a "minimum" (i.e., zero derivative) in the de-oxy absorbance signal.

Examples of the disclosure can include at least one light emitter (e.g., light emitter 206 illustrated in FIG. 2A, light emitter 306 illustrated in FIG. 3A) configured to emit within wavelength range 764 (i.e., 495-570 nm). Examples of the disclosure can include at least one light emitter (e.g., light emitter 308 illustrated in FIG. 3A) configured to emit within wavelength range 765 (i.e., 570-750 nm). Examples of the disclosure can include at least two light emitters (e.g., light emitter 306 and light emitter 308 illustrated in FIG. 3A) configured to emit within the same wavelength range (e.g., wavelength range 764, wavelength range 765, and/or wavelength range 767). Examples of the disclosure can include at least one light emitter (e.g. light emitter 308 illustrated in FIG. 3A) configured to emit within wavelength ranges 966 and 967 (i.e., 750-1400 nm).

Examples of the disclosure can include a system capable of emitting light across a spectrum of wavelengths or a plurality of wavelength (e.g., greater than two wavelengths). For example, the system can include at least one light emitter (e.g., light emitter 606 illustrated in FIG. 6A) configured to emit light within wavelength range 964 (i.e., 495-570 nm), at least one light emitter (e.g., light emitter 605 illustrated in FIG. 6A) configured to emit light within wavelength range 966 and wavelength range 967 (i.e., 750-1400 nm), and at least one light emitter (e.g., light emitter 608 illustrated in FIG. 6A) configured to emit light within wavelength range 965 (i.e., 570-750 nm). In some examples, one light emitter can be configured to emit at 525 nm, one light emitter can be configured to emit at 660 nm, and one light emitter can be configured to emit at 890 nm. Measuring reflected light within wavelength range 965 can lead to signals with little-to-no pulsatile blood information. Measuring reflected light within wavelength range 966 and wavelength range 967 can lead to light that can be invisible to the user's eye. Examples of the disclosure can include a

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system configured with a common (i.e., shared) light emitter capable of emitting light to a plurality of light sensors, where at least one set of light emitter-light sensor can be configured for measuring pulsatile blood flow and at least one set of (the same) light emitter-light sensor can be configured for measuring non-pulsatile blood flow.

In some examples, at least two sets of light emitter-light sensor can be configured to measure (e.g., light passes through) the same volume of the user's skin. By measuring the same volume of skin, the non-pulsatile blood information can be accurately associated with the corresponding pulsatile blood information. In some examples, at least two light emitters and optically coupled one or more detectors can be located along the same optical axis.

In some examples, at least two sets of light emitter-light sensor can be configured to measure different volumes of the user's skin. The locations of optical components in such a configuration may be limited due to the size of a package or the separation distance between optical components, for example.

FIG. 9B illustrates exemplary signals measured at the plurality of light sensors included in an exemplary electronic device according to examples of the disclosure. Signal 950 can include pulsatile blood information and noise artifacts. Signal 955 can include noise artifacts using any of the above disclosed examples. In some examples, signal 950 can be the signal generated by one of the sets of light emitter-light sensor. In some examples, signal 955 can be the signal generated by another one of the sets of light emitter-light sensor. The PPG system can include a controller configured to determine a user's physiological signal by removing noise artifacts from signal 950. In some examples, at least a portion of the noise artifacts included in signal 950 can be determined using signal 955. For example, frequency 971 can correspond to a fundamental frequency for the user's physiological signal (e.g., PPG), and frequency 972 can correspond to a harmonic frequency for the user's physiological signal. The controller can be configured to determine the fundamental and harmonic frequencies and can utilize signal 950 and signal 955 to determine the user's physiological signal.

In some examples, signals associated with one or more light emitters (e.g., light emitter 306 and light emitter 316) can be used for determining the user's physiological signals while the user is in motion. In some examples, signals associated with one or more light emitters (e.g., light emitter 306 and light emitter 316) can be used for determining the user's physiological signals while the user is stationary. In some examples, one or more signals can include heart rate PPG signals. In some examples, one or more signals can be used for off-wrist detection (i.e., the device is located a far distance away from the user). In some examples, the device can include an accelerometer to detect the user's acceleration, and such acceleration information can additionally be used for canceling/correcting motion artifacts in the user's physiological signal. In some examples, one or more of the light emitters and/or light sensors can be disabled, powered off, or their signals can be ignored. For example, light emitter 308 and/or light emitter 316 (illustrated in FIG. 3A) can be powered off when the user is moving.

FIG. 10A illustrates an exemplary circuit diagram and FIG. 10B illustrates an exemplary process for motion artifact removal according to examples of the disclosure. The system can include light emitter 1006 optically coupled to light sensor 1004 and light emitter 1005 optically coupled to light sensor 1007. Light emitter 1006 can emit light towards light sensor 1004 (step 1052 of process 1050). Light sensor

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1004 can detect the reflected light from light emitted by light emitter 1006 and can generate a signal 1050 (step 1054 of process 1050). The Fourier transform of signal 1050 can be taken using FFT 1010 (step 1056 of process 1050). Light emitter 1005 can emit light towards light sensor 1007 (step 1058 of process 1050). Light sensor 1007 can detect the reflected light from light emitted by light emitter 1005 and can generate a signal 1055 (step 1060 of process 1050). In some examples, light emitter 1005 can emit light at the same time as light emitter 1006. The Fourier transfer of signal 1055 can be taken using FFT 1010 (step 1062 of process 1050). The locations of the peaks (i.e., "maximum"/zero derivative) in signal 1050 and signal 1055 can be determined using component 1011 (step 1064 of process 1050). In some examples, the values of signal 1050 can be scaled (e.g., a Gaussian weight can be applied) at locations where a peak exists (step 1066 of process 1050). In some examples, the corrected (or adjusted) signal 1050 can include peaks from the fundamental and harmonic frequencies of the user's physiological signal.

The system can further include an accelerometer 1002. Accelerometer 1002 can measure the user's acceleration (step 1068 of process 1050). In some examples, the acceleration measurement can be concurrent with the optical measurements from the light sensors. The Fourier transform of the acceleration signal can be taken using FFT 1010 (step 1070 of process 1050). The locations of the peaks in the corrected signal 1050 and acceleration signal can be determined using component 1011 (step 1072 of process 1050). Controller 1009 can apply one or more algorithms and/or simple mathematical functions to determine the user's physiological signal 1060 (step 1074 of process 1050).

FIG. 11A illustrates an exemplary circuit diagram and FIG. 11B illustrates an exemplary process for motion artifact removal according to examples of the disclosure. The system can include light emitter 1106 optically coupled to light sensor 1104 and light emitter 1105 optically coupled to light sensor 1107. Light emitter 1106 can emit light towards light sensor 1104 (step 1152 of process 1150). Light sensor 1104 can detect the reflected light from light emitted by light emitter 1106 and can generate a signal 1150 (step 1154 of process 1150). The Fourier transform of signal 1150 can be taken (step 1160 of process 1150).

Light emitter 1105 can emit light towards light sensor 1107 (step 1162 of process 1150). Light sensor 1107 can detect the reflected light from light emitted by light emitter 1105 and can generate a signal 1155 (step 1164 of process 1150). The system can further include an accelerometer 1102. Accelerometer 1102 can measure the user's acceleration (step 1156 of process 1150). In some examples, the acceleration measurement can be concurrent with the optical measurements from the light sensors. Principle component analysis (PCA) can be performed on signal 1155 and the acceleration signal using motion estimator 1103 (step 1158 of process 1150). PCA 1102 can be configured to utilize an orthogonal transformation to convert signal 1155 and the acceleration signal into three orthogonal components. The Fourier transform of the orthogonal components can be taken using FFT 1110 (step 1166 of process 1150).

The locations of the peaks in the signals from both FFTs 1110 can be determined using component 1111 (step 1168 of process 1150). In some examples, one or more gait frequencies in signal 1150 can be determined. At the one or more gait frequencies, the signals can be attenuated. The controller 1009 can be configured to apply one or more algorithms and/or simple mathematical functions to determine the user's physiological signal 1160 (step 1170 of process 1150).

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In the one or more of the above disclosed systems, the sets of light emitter-light sensor can be operated serially or in parallel (i.e., concurrently). FIGS. 12A-12C illustrate exemplary measurement modes according to examples of the disclosure. The PPG system can include light emitter 1206, light emitter 1208, light emitter 1216, light emitter 1218, light sensor 1204, and light sensor 1214.

As illustrated in FIG. 12A, the system can be configured to cycle through the sets. Between time  $t_0$  and  $t_1$ , light emitter 1206 can be active/on. Light sensor 1204 can measure the reflected light from light emitter 1206 followed by light sensor 1214 measuring the reflected light from light emitter 1206. Between time  $t_1$  and time  $t_2$ , light emitter 1208 can be active/on. Light sensor 1204 can measure the reflected light from light emitter 1208, followed by light sensor 1214 measuring the reflected light from light emitter 1208. Between time  $t_2$  and time  $t_3$ , light emitter 1216 can be active/on. Light sensor 1204 can measure the reflected light from light emitter 1216, followed by light sensor 1214 measuring the reflected light from light emitter 1216. Between time  $t_3$  and time  $t_4$ , light emitter 1218 can be active/on. Light sensor 1204 can measure the reflected light from light emitter 1218, followed by light sensor 1214 measuring the reflected light from light emitter 1218. Between time  $t_4$  and time  $t_5$ , the system can be configured for off-wrist detection. In some examples, the cycle can be repeated. In some examples, subsequent cycles can have a different order.

The system can further include light emitter 1205 and light emitter 1215. As illustrated in FIG. 12B, the measurements can include operation of those additional light emitters in time periods following the operation of all other light emitters. Between time  $t_4$  and time  $t_5$ , light emitter 1205 can be active/on. Light sensor 1204 can measure the reflected light from light emitter 1205, followed by light sensor 1214 measuring the reflected light from light emitter 1205. Between time  $t_5$  and time  $t_6$ , light emitter 1215 can be active/on. Light sensor 1204 can measure the reflected light from light emitter 1215, followed by light sensor 1214 measuring the reflected light from light emitter 1215. Between time  $t_6$  and time  $t_7$ , the system can be configured for off-wrist detection. In some examples, the cycle can be repeated. In some examples, subsequent cycles can have a different order.

In some examples, two or more measurements can operate concurrently. As illustrated in FIG. 12C, a first measurement and a second measurement can operate concurrently between time  $t_0$  and  $t_1$ . The first measurement can include light emitter 1206 active/on, while light sensor 1204 measures the reflected light and light sensor 1214 measures the reflected light. The second measurement can include light emitter 1205 active/on, while light sensor 1207 measures the reflected light and light sensor 1217 measures the reflected light. In some examples, the measurements can operate in a staggered (i.e., the start of one measurement can be delayed from the start of another measurement). In some examples, a time period can include the first measurement having a different set of light emitter-light sensor (e.g., light emitter 1208, light sensor 1204, and light sensor 1214), while the second measurement can be the same (e.g., light emitter 1205, light sensor 1207, and light sensor 1217), as illustrated between time  $t_1$  and  $t_2$ . In some examples, a time period can include the first measurement having the same set of light emitter-light sensor (e.g., light emitter 1206, light sensor 1204, and light sensor 1214), as illustrated between time  $t_2$  and  $t_3$ . In some examples, a time period can include more than two measurements operating concurrently. For

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example, all the measurements can be taken at the same time (not shown). In some examples, off-wrist detection can occur at any time between measurements or concurrently with measurements.

FIG. 13A illustrates an exemplary process illustrating time-based operation of a PPG system according to examples of the disclosure. The first light emitter can emit light towards the first light sensor (step 1302 of process 1300). The first light sensor can generate the first signal indicative of the reflection from the first light emitter (step 1304 of process 1300). The second light emitter can emit light towards the second light sensor (step 1306 of process 1300). The second light sensor can generate a second signal indicative of the reflection from the second light emitter (step 1308 of process 1300). In some examples, first light emitter can operate concurrently with the second light emitter. In some examples, first light emitter can operate before second light emitter. In some examples, second light emitter can operate before first light emitter. The second signal can be compared to a threshold value (step 1310 of process 1300), and a controller can determine whether noise correction should be performed (step 1312 of process 1300). If noise correction is to be performed, the first signal can be corrected or adjusted with the second signal (step 1314 of process 1300). One or more algorithms can be applied to determine the user's physiological signal(s) (step 1316 of process 1300).

FIG. 13B illustrates an exemplary process illustrating operation of a PPG system including a light emitter-light sensor set for motion detection according to examples of the disclosure. The first light emitter can emit light towards the first light sensor (step 1332 of process 1330). The first light sensor can generate the first signal indicative of the reflection from the first light emitter (step 1334 of process 1330). The second light emitter can emit light towards the second light sensor (step 1336 of process 1330). The second light sensor can generate the second signal indicative of the reflection from the second light emitter (step 1338 of process 1330). An accelerometer can detect the user's acceleration and generate an acceleration signal (step 1344 of process 1330). The acceleration signal can be compared to a threshold value (step 1346 of process 1330). A controller can determine whether optical-based noise correction should be performed (step 1348 of process 1330), and if so, the first signal can be corrected or adjusted with the second signal (step 1340 of process 1330). If not, the controller can determine whether acceleration-based noise correction should be performed (step 1350 of process 1330). If so, the first signal can be corrected or adjusted with the acceleration signal (step 1342 of process 1330). One or more algorithms can be applied to determine the user's physiological signal(s) (step 1352 of process 1330).

FIG. 13C illustrates an exemplary process illustrating operation of a PPG system including an accelerometer for motion detection according to examples of the disclosure. The first light emitter can emit light towards first light sensor (step 1362 of process 1360). The first light sensor can generate the first signal indicative of the reflection from the first light emitter (step 1364 of process 1360). An accelerator can detect the user's motion and generate an acceleration signal (step 1366 of process 1360). A controller can determine whether the user is moving (step 1368 of process 1360). If the user is moving, the second light emitter can emit light towards second light sensor (step 1370 of process 1360). The second light sensor can detect the reflected light and generate a second signal (step 1372 of process 1330). In some examples, the second light sensor can remain in an

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inactive state until the accelerometer detects user movement. The first signal can be corrected or adjusted using the second signal (step 1374 of process 1330). A controller can apply one or more algorithms to determine the user's physiological signal(s) (step 1376 of process 1330).

FIG. 13D illustrates an exemplary process illustrating operation of a PPG system according to examples of the disclosure. An accelerometer can detect user motion (step 1382 of process 1380). If user motion is detected, a first light emitter can emit light towards a first light sensor (step 1384 of process 1380). The first light sensor can generate a first signal indicative of the reflection from the first light emitter (step 1386 of process 1380). A second light emitter can emit light towards a second light sensor (step 1388 of process 1380). The second light sensor can generate a second signal indicative of the reflection from the second light emitter (step 1390 of process 1380). The first signal can be corrected or adjusted using the second signal (step 1392 of process 1380). If user motion has not been detected, a third light emitter can emit light towards the first light sensor (step 1394 of process 1380). The first light sensor can generate a third signal indicative of the reflection from the third light emitter (step 1396 of process 1380). A controller can apply one or more algorithms to determine the user's physiological signal(s) (step 1398 of process 1380).

FIG. 14 illustrates an exemplary block diagram of a computing system comprising light emitters and light sensors for measuring a signal associated with a user's physiological state according to examples of the disclosure. Computing system 1400 can correspond to any of the computing devices illustrated in FIGS. 1A-1C. Computing system 1400 can include a processor 1410 configured to execute instructions and to carry out operations associated with computing system 1400. For example, using instructions retrieved from memory, processor 1410 can control the reception and manipulation of input and output data between components of computing system 1400. Processor 1410 can be a single-chip processor or can be implemented with multiple components.

In some examples, processor 1410 together with an operating system can operate to execute computer code and produce and use data. The computer code and data can reside within a program storage block 1402 that can be operatively coupled to processor 1410. Program storage block 1402 can generally provide a place to hold data that is being used by computing system 1400. Program storage block 1402 can be any non-transitory computer-readable storage medium, and can store, for example, history and/or pattern data relating to PPG signal and perfusion index values measured by one or more light sensors such as light sensors 1404. By way of example, program storage block 1402 can include Read-Only Memory (ROM) 1418, Random-Access Memory (RAM) 1422, hard disk drive 1408 and/or the like. The computer code and data could also reside on a removable storage medium and loaded or installed onto the computing system 1400 when needed. Removable storage mediums include, for example, CD-ROM, DVD-ROM, Universal Serial Bus (USB), Secure Digital (SD), Compact Flash (CF), Memory Stick, Multi-Media Card (MMC) and a network component.

Computing system 1400 can also include an input/output (I/O) controller 1412 that can be operatively coupled to processor 1410, or it can be a separate component as shown. I/O controller 1412 can be configured to control interactions with one or more I/O devices. I/O controller 1412 can operate by exchanging data between processor 1410 and the I/O devices that desire to communicate with processor 1410.

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The I/O devices and I/O controller **1412** can communicate through a data link. The data link can be a one-way link or a two-way link. In some cases, I/O devices can be connected to I/O controller **1412** through wireless connections. By way of example, a data link can correspond to PS/2, USB, Firewire, IR, RF, Bluetooth or the like.

Computing system **1400** can include a display device **1424** that can be operatively coupled to processor **1410**. Display device **1424** can be a separate component (peripheral device) or can be integrated with processor **1410** and program storage block **1402** to form a desktop computer (e.g., all-in-one machine), a laptop, handheld or tablet computing device of the like. Display device **1424** can be configured to display a graphical user interface (GUI) including perhaps a pointer or cursor as well as other information to the user. By way of example, display device **1424** can be any type of display including a liquid crystal display (LCD), an electroluminescent display (ELD), a field emission display (FED), a light emitting diode display (LED), an organic light emitting diode display (OLED) or the like.

Display device **1424** can be coupled to display controller **1426** that can be coupled to processor **1410**. Processor **1410** can send raw data to display controller **1426**, and display controller **1426** can send signals to display device **1424**. Data can include voltage levels for a plurality of pixels in display device **1424** to project an image. In some examples, processor **1410** can be configured to process the raw data.

Computing system **1400** can also include a touch screen **1430** that can be operatively coupled to processor **1410**. Touch screen **1430** can be a combination of sensing device **1432** and display device **1424**, where the sensing device **1432** can be a transparent panel that is positioned in front of display device **1424** or integrated with display device **1424**. In some cases, touch screen **1430** can recognize touches and the position and magnitude of touches on its surface. Touch screen **1430** can report the touches to processor **1410**, and processor **1410** can interpret the touches in accordance with its programming. For example, processor **1410** can perform tap and event gesture parsing and can initiate a wake of the device or powering on one or more components in accordance with a particular touch.

Touch screen **1430** can be coupled to a touch controller **1440** that can acquire data from touch screen **1430** and can supply the acquired data to processor **1410**. In some cases, touch controller **1440** can be configured to send raw data to processor **1410**, and processor **1410** can process the raw data. For example, processor **1410** can receive data from touch controller **1440** and can determine how to interpret the data. The data can include the coordinates of a touch as well as pressure exerted. In some examples, touch controller **1440** can be configured to process raw data itself. That is, touch controller **1440** can read signals from sensing points **1434** located on sensing device **1432** and can turn the signals into data that the processor **1410** can understand.

Touch controller **1440** can include one or more microcontrollers such as microcontroller **1442**, each of which can monitor one or more sensing points **1434**. Microcontroller **1442** can, for example, correspond to an application specific integrated circuit (ASIC), which works with firmware to monitor the signals from sensing device **1432**, process the monitored signals, and report this information to processor **1410**.

One or both display controller **1426** and touch controller **1440** can perform filtering and/or conversion processes. Filtering processes can be implemented to reduce a busy data stream to prevent processor **1410** from being over-

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loaded with redundant or non-essential data. The conversion processes can be implemented to adjust the raw data before sending or reporting them to processor **1410**.

In some examples, sensing device **1432** can be based on capacitance. When two electrically conductive members come close to one another without actually touching, their electric fields can interact to form a capacitance. The first electrically conductive member can be one or more of the sensing points **1434**, and the second electrically conductive member can be an object **1490** such as a finger. As object **1490** approaches the surface of touch screen **1430**, a capacitance can form between object **1490** and one or more sensing points **1434** in close proximity to object **1490**. By detecting changes in capacitance at each of the sensing points **1434** and noting the position of sensing points **1434**, touch controller **1440** can recognize multiple objects, and determine the location, pressure, direction, speed and acceleration of object **1490** as it moves across the touch screen **1430**. For example, touch controller **1440** can determine whether the sensed touch is a finger, tap, or an object covering the surface.

Sensing device **1432** can be based on self-capacitance or mutual capacitance. In self-capacitance, each of the sensing points **1434** can be provided by an individually charged electrode. As object **1490** approaches the surface of the touch screen **1430**, the object can capacitively couple to those electrodes in close proximity to object **1490**, thereby stealing charge away from the electrodes. The amount of charge in each of the electrodes can be measured by the touch controller **1440** to determine the position of one or more objects when they touch or hover over the touch screen **1430**. In mutual capacitance, sensing device **1432** can include a two layer grid of spatially separated lines or wires (not shown), although other configurations are possible. The upper layer can include lines in rows, while the lower layer can include lines in columns (e.g., orthogonal). Sensing points **1434** can be provided at the intersections of the rows and columns. During operation, the rows can be charged, and the charge can capacitively couple from the rows to the columns. As object **1490** approaches the surface of the touch screen **1430**, object **1490** can capacitively couple to the rows in close proximity to object **1490**, thereby reducing the charge coupling between the rows and columns. The amount of charge in each of the columns can be measured by touch controller **1440** to determine the position of multiple objects when they touch the touch screen **1430**.

Computing system **1400** can also include one or more light emitters such as light emitters **1406** and one or more light sensors such as light sensors **1404** proximate to skin **1420** of a user. Light emitters **1406** can be configured to generate light, and light sensors **1404** can be configured to measure a light reflected or absorbed by skin **1420**, vasculature, and/or blood of the user. Device **1400** can include a plurality of sets of light emitter-light sensor. At least one of the sets of light emitter-light sensor can be configured to measure pulsatile blood, and at least one of the sets of light emitter-light sensor can be configured to measure non-pulsatile blood. In some examples, device **1400** can include an accelerometer (not shown). Light sensor **1404** can send measured raw data to processor **1410**, and processor **1410** can perform noise and/or artifact cancelation to determine the PPG signal and/or perfusion index. Processor **1410** can dynamically activate light emitters and/or light sensors and dynamically reconfigure the aperture properties based on an application, user skin type, and usage conditions. In some examples, some light emitters and/or light sensors can be activated, while other light emitters and/or light sensors can

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be deactivated to conserve power, for example. In some examples, processor 1410 can store the raw data and/or processed information in a ROM 1418 or RAM 1422 for historical tracking or for future diagnostic purposes.

In some examples, the light sensors can measure light information and a processor can determine a PPG signal and/or perfusion index from the reflected or absorbed light. Processing of the light information can be performed on the device as well. In some examples, processing of light information need not be performed on the device itself. FIG. 15 illustrates an exemplary configuration in which an electronic device is connected to a host according to examples of the disclosure. Host 1510 can be any device external to device 1500 including, but not limited to, any of the systems illustrated in FIGS. 1A-1C or a server. Device 1500 can be connected to host 1510 through communications link 1520. Communications link 1520 can be any connection including, but not limited to, a wireless connection and a wired connection. Exemplary wireless connections include Wi-Fi, Bluetooth, Wireless Direct and Infrared. Exemplary wired connections include Universal Serial Bus (USB), FireWire, Thunderbolt, or any connection requiring a physical cable.

In operation, instead of processing light information from the light sensors on the device 1500 itself, device 1500 can send raw data 1530 measured from the light sensors over communications link 1520 to host 1510. Host 1510 can receive raw data 1530, and host 1510 can process the light information. Processing the light information can include canceling or reducing any noise due to artifacts and determining physiological signals such as a user's heart rate. Host 1510 can include algorithms or calibration procedures to account for differences in a user's characteristics affecting PPG signal and perfusion index. Additionally, host 1510 can include storage or memory for tracking a PPG signal and perfusion index history for diagnostic purposes. Host 1510 can send the processed result 1540 or related information back to device 1500. Based on the processed result 1540, device 1500 can notify the user or adjust its operation accordingly. By offloading the processing and/or storage of the light information, device 1500 can conserve space and power-enabling device 1500 to remain small and portable, as space that could otherwise be required for processing logic can be freed up on the device.

An electronic device is disclosed. The electronic device can comprise: one or more first light emitters configured to generate a first light; one or more first light sensors configured to detect a reflection of the first light and configured to generate a first signal indicative of the reflection of the first light, the first signal including non-pulsatile blood information; and logic coupled to the one or more first light sensors, the logic configured to: receive the first signal, and determine at least a portion of a physiological signal from the first signal. Additionally or alternatively, in some examples, the device can further comprise: one or more second light sensors configured to detect a reflection of a second light and configured to generate a second signal indicative of the reflection of the second light, the second light generated by the one or more first light emitters and the second signal including pulsatile blood information, wherein the logic is further coupled to the one or more second light sensors, and further configured to receive the second signal and include the second signal in the determination of the physiological signal. Additionally or alternatively, in some examples, the one or more first light emitters, one or more first light sensors, and one or more second light sensors are located along a common optical axis. Additionally or alternatively, in some examples, the device further comprises: one or more

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second light emitters configured to generate a second light, wherein the one or more first light sensors are further configured to generate a second signal indicative of the reflection of the second light, the second signal including pulsatile blood information, wherein the logic is further configured to receive the second signal and include the second signal in the determination of the physiological signal. Additionally or alternatively, in some examples, the one or more first light emitters, one or more first light sensors, and one or more second light emitters are located along a common optical axis. Additionally or alternatively, in some examples, the device further comprises: one or more second light emitters configured to generate a second light; and one or more second light sensors configured to detect a reflection of the second light and configured to generate a second signal indicative of the reflection of the second light, the second signal including pulsatile blood information, wherein logic is further coupled to the one or more second light sensors and is further configured to receive the second signal and include the second signal in the determination of the physiological signal. Additionally or alternatively, in some examples, the one or more second light emitters and the one or more second light sensors are located in different cavities. Additionally or alternatively, in some examples, the second light includes light with a wavelength between 570-750 nm. Additionally or alternatively, in some examples, the second light includes light with a wavelength between 495-570 nm. Additionally or alternatively, in some examples, the first light and second light intersect. Additionally or alternatively, in some examples, the device further comprises: one or more third light emitters configured to generate a third light, wherein the one or more second light sensors are further configured to detect a reflection of the third light and configured to generate a third signal indicative of the reflection of the third light, the third signal including pulsatile blood information, wherein logic is further configured to receive the third signal and include the third signal in the determination of the physiological signal. Additionally or alternatively, in some examples, the first light includes light with a wavelength between 570-750 nm, the second light includes light with a wavelength between 495-570 nm, and the third light includes light with a wavelength between 750-1400 nm. Additionally or alternatively, in some examples, the one or more first light emitters and the one or more first light sensors are located in a same cavity. Additionally or alternatively, in some examples, the first light includes light with a wavelength between 495-570 nm. Additionally or alternatively, in some examples, at least one of the one or more first light emitters is spaced less than 1 mm from at least one of the one or more first light sensors. Additionally or alternatively, in some examples, the device further comprises: an isolation configured to optically isolate at least one of the one or more first light emitters from at least one of the one or more first light sensors. Additionally or alternatively, in some examples, the device further comprises: a window optically coupled to at least one of the one or more first light emitters, wherein an end of the isolation contacts an inner surface of the window, the inner surface located closer to the one or more first light emitters than an outer surface of the window. Additionally or alternatively, in some examples, the device further comprises: a window optically coupled to at least one of the one or more first light emitters, wherein a first end of the isolation contacts an outer surface of the window, the outer surface located further from the one or more first light emitters than an inner surface of the window. Additionally or alternatively, in some examples, the isolation includes a

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continuous section disposed between the first end and a second end, the second end located proximate to the at least one of the one or more first light emitters. Additionally or alternatively, in some examples, the isolation comprises: a first section disposed between the first end and a third end, the third end located at the inner surface of the window, and a second section disposed between the third end and a second end, the second end located proximate to the at least one of the one or more first light emitters. Additionally or alternatively, in some examples, the device further comprises: a second isolation, wherein a first end of the isolation is laterally spaced a first distance away from the second isolation and a second end of the isolation is laterally spaced a second distance, different from the first distance, away from the second isolation.

A method for determining a physiological signal is disclosed. The method can comprise: emitting a first light at a user; detecting a reflection of the first light; generating a first signal indicative of the detected reflection of the first light, the first signal including non-pulsatile blood information; emitting a second light at the user; detecting a reflection of the second light; generating a second signal indicative of the detected reflection of the second light, the second signal including pulsatile blood information; adjusting the second signal to compensate for information included in the first signal; and determining the physiological signal based on the adjusted second signal. Additionally or alternatively, in some examples, the first light is emitted at a first portion of the user and the second light is emitted at a second portion, different from the first portion, of the user. Additionally or alternatively, in some examples, the first and second light are emitted at a first portion of the user. Additionally or alternatively, in some examples, the method further comprises: determining one or more peaks included in the first and second signals; and determining one or more locations of the one or more peaks, wherein adjusting the second signal includes scaling the second signal at the one or more locations. Additionally or alternatively, in some examples, the method further comprises: detecting an acceleration of the user; and generating a third signal indicative of the acceleration, wherein adjusting the second signal further includes information included in the third signal. Additionally or alternatively, in some examples, the method further comprises: detecting an acceleration of the user; generating a third signal indicative of the acceleration; comparing the third signal to a threshold value, wherein the second light is emitted at the user when the third signal is greater than or equal to the threshold value.

The light emitter(s) and light sensor(s) may be located such that their illumination field(s) and field-of-view(s), respectively, extend from the back surface of the device housing. In some variations, at least a portion of the back surface of the device housing (e.g., the underside of a wearable device) may contact skin when worn by an individual. The back surface of the device may comprise one or more protrusions or raised regions that may be optionally sized and shaped to facilitate skin contact, and/or apply pressure to the skin in order to facilitate movement of non-pulsatile blood away from skin regions that are within, or in the vicinity of, the illumination field(s) and/or field-of-view(s) of the light emitter(s) and light sensor(s) when the device is worn by the individual (e.g., attached to the wrist, arm, chest, leg, etc.). Since non-pulsatile blood flow may be a significant contributor of motion artifacts in pulsatile blood measurements, reducing the flow of non-pulsatile blood in this region this may help to improve the optical measurements of pulsatile blood.

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In some variations, the protrusions may have one or more curves or contours that apply pressure to the skin when the device is worn by the individual. For example, the one or more protrusions may comprise one or more curves or contours that may be convex, and/or concave, and/or convex in some regions and concave in other regions. In some variations, the convex regions of the one or more protrusions may be disposed over the light paths of the light emitter(s) and/or light sensor(s). In other variations, the concave regions of the one or more protrusions may be disposed over the light paths of the light emitter(s) and/or light sensor(s). The one or more protrusions may comprise transparent and/or opaque regions. The regions of the protrusion(s) that are located within the illumination field and/or field-of-view (i.e., optical path or light path) of the light emitter(s) and light sensor(s) may be transparent or translucent, while other regions of the protrusion may be opaque. For example, one or more protrusions may be disposed within the optical path of the light emitter(s) and/or light sensor(s). The back surface (i.e., underside of the device) may comprise an opening or a window in the housing that is aligned with the illumination field and/or field-of-view of the light emitter(s) and/or light sensor(s) and an optically transparent cover structure disposed over or within the opening. For example, the cavity within which the light emitter(s) and/or light sensor(s) reside may comprise an opening or window. The cover structure may be flush with respect to the housing surface, or may be concave or convex. In some variations, a protrusion may comprise a convex cover structure. Some protrusions or cover structures may comprise an optical barrier or isolation as described herein that extends through the thickness of the protrusion. The isolation may obstruct or prevent light from one side of the barrier from interfering with light from the other side of the barrier. In some variations, the isolation may extend continuously from within the cavity and through the thickness of the protrusion. The isolation may be a single component that extends through the cavity and the protrusion, or may be comprised of one or more isolation segments that connected together. The isolation may be approximately parallel to the optical path of the emitters or detectors. The size and shape of an optical opening or window of a cavity may correspond with the size and shape of the illumination field and/or field-of-view of the light emitter(s) and/or light sensor(s). Alternatively or additionally, the diameter of an optical opening or window may vary from about 1 mm to about 20 mm, for example, about 3 mm, about 4 mm, about 5 mm, about 6 mm, about 8 mm, about 10 mm, about 12 mm, about 15 mm, etc., for example, about 5.4 mm, about 6.4 mm.

Some variations of a wrist-worn device may have a housing that comprises a protrusion that circumscribes and/or at least partially surrounds and/or encloses the optical opening(s) or window(s) of one or more cavities within which the light emitter(s) and/or light sensor(s) are disposed. The protrusion may not be located in the optical path of the light emitter(s) and/or light sensor(s). One variation of a protrusion that at least partially surrounds the one or more optical openings of one or more cavities of a device is depicted in FIGS. 16A-16B. FIG. 16A depicts a back surface 1600 of a wrist-worn device (such as any of the devices depicted in FIGS. 1A-1C), and a protrusion 1602 that at least partially surrounds the optical openings 1604 of the cavities of the device. One or more optical components (e.g., light emitter(s), light sensor(s), or a combination thereof) may be located within the housing of the device and aligned with an optical opening 1604 of a corresponding cavity. A transparent or translucent cover structure may be disposed over or

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within each of the optical openings or cavities. The protrusion 1602 may be ring-shaped, which may be an open or closed ring. In still other variations, the protrusion may be arc-shaped. The enclosed region 1606 of the underside or back surface 1600 that is surrounded by the protrusion 1602 may have a convex curvature, as depicted in FIG. 16B, or may have a concave curvature. In still other variations, the enclosed region 1606 may not have any curves, and may be substantially flat. As depicted in FIG. 16A, the protrusion 1602 may surround all of the optical openings 1604 and corresponding cavities, but it should be understood that the protrusion 1602 might surround a subset of the openings and corresponding cavities. For example, some devices may comprise a first protrusion that surrounds a first set of the cavities and a second protrusion that surrounds a second set of the cavities. A device may comprise two or more protrusions that may not surround or enclose any of the cavities, but may span a length or width of the housing of the device. FIG. 16B depicts a side view of the back surface 1600 having a ring-shaped protrusion 1602 when attached to skin 1608 of an individual. In this example, the protrusion 1602 may apply pressure that is focused in a ring around the optical windows 1604. That is, the skin area under the protrusion 1602 may be displaced more (i.e., subject to greater levels of pressure) than the skin area under the region 1606 or optical openings 1604. A protrusion that surrounds the optical openings and/or corresponding cavities may subject skin that surrounds the optical openings and/or corresponding cavities to greater levels of pressure as compared to skin located directly underneath the optical openings and/or corresponding cavities. As described previously, the optical components that are disposed within each of the cavities that correspond to each of the optical openings 1604 may comprise one or more light emitters, one or more light sensors, or a combination of one or more light emitters and one or more light sensors, as described above. The cover structures may each include an isolation that extends from the cavity and through the thickness of the cover structure.

In some variations, the underside or back surface of a device may comprise a protrusion that comprises a raised region that extends from the surface of the housing. The cavities within which the light emitter(s) and/or light sensor(s) and their corresponding optical openings may be located on the protrusion. For example, the protrusion may form a plateau that extends from the surface of the housing, and the optical openings and/or corresponding cavities may be located on the surface of the plateau. The plateau may extend over or across a substantial portion of the area of the back surface (e.g., the surface area of the plateau may be about 30%, or about 40%, or about 50% or about 60% or more, of the surface area of the entire back surface). For example, the surface area of the plateau may be approximately the same as the surface area of the underside or back surface (e.g., covers the entire back surface), or the surface area of the plateau may be about 20% less, about 30% less, about 40%, about 50% less than the surface area of the back surface. One variation of a device having a back surface that comprises a protrusion or raised region that extends from and across the back surface is depicted in FIGS. 17A-17B. Underside or back surface 1700 may comprise a protrusion 1702 comprising a surface that is raised relative to the other regions 1706 of the back surface 1700. The device may comprise four optical openings 1704 corresponding to four cavities that are located on the raised surface of the protrusion 1702. The surface of the protrusion 1702 that contacts the skin may be flat (i.e., without any curves), or may have a convex curve, as depicted in FIGS. 17A and 17B. The cover

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structures disposed over or within the optical openings 1704 may be flush with the surface of the protrusion 1702, or may protrude even further from the surface of the protrusion 1702. FIG. 17B depicts a side view of the back surface 1700 when attached to skin 1708 of an individual. The skin regions in contact with the protrusion 1702 may be subject to greater levels of pressure as compared to the skin in contact with the non-raised regions 1706 of the back surface 1700, as schematically represented by the arrows in FIG. 17B. That is, the skin region directly underneath and in the vicinity of the optical openings may be subject to increased pressure levels. While the protrusion 1702 is depicted as having a circular shape, it should be understood that the protrusion might have any shape (e.g., ellipse, oval, rectangle, etc.). In other variations, a back surface may comprise two or more raised regions or protrusions that are co-located with the optical openings. For example, a back surface may comprise a first semi-circular protrusion that extends over the portions of the back surface that include a first subset of the cavities and/or corresponding optical openings and a second semi-circular protrusion that extends over the portions of the back surface that includes a second subset of the cavities and/or corresponding optical openings. As described previously, the optical components that are disposed within each of the cavities that correspond to each of the optical openings 1704 may comprise one or more light emitters, one or more light sensors, or a combination of one or more light emitters and one or more light sensors, as described above. The cover structures may each include an isolation that extends from the cavity and through the thickness of the cover structure.

In some variations, a back surface of a wearable device may be similar to the protrusion(s) described above and depicted in FIGS. 17A and 17B, however, the protrusion(s) may comprise one or more recessed regions within which the optical opening or windows of the cavities may be located. The surface of the cover structure disposed over each optical window may be set within each recess such that the cover structure surface is not flush with, nor does it extend beyond, the surface of the protrusion. One variation is depicted in FIG. 18A. As depicted there, back surface 1800 of a wearable device may comprise a protrusion 1802 that comprises recesses (i.e., recessed regions) 1803 that are each located over an optical opening or window 1804. That is, the cavities within which the light emitter(s) and/or light sensor(s) are located may themselves be located within a recess of a protrusion. The height of the cover structures located over each of the optical openings may not exceed the depth of each of the recesses 1803. FIG. 18C depicts a side view of the back surface 1800 when contacting skin 1808 of an individual. The skin regions in contact with the regions 1805 of the protrusion 1802 between the recessed regions 1803 or optical windows 1804, or outside of the recessed regions (e.g., around or near the outer edge or perimeter of the protrusion 1802) may be subject to higher levels of pressure as compared to the skin regions in contact with the recessed regions 1803 and/or cover structures of the optical openings 1804. For example, skin regions that may be subject to increased pressure levels are represented by the arrows in FIG. 18C. The surface area of the protrusion 1802 may be similar to the surface area of the back surface 1800, as depicted in FIG. 18A, or may be less than the surface area of the back surface 1810, as depicted in FIG. 18B. As depicted there, the protrusion 1812 may comprise recesses 1813 disposed over the optical openings or windows 1814, as described previously. The surface area of the protrusion 1812 may be about 20% less, about 30% less, about 40%,



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about 50% less than the surface area of the back surface **1810**. The skin regions that contact the regions **1816** of the back surface that surround the protrusion **1812**, or that contact the recessed regions **1813** of the protrusion **1812** may be subject to reduced levels of pressure as compared to the skin regions in contact with the protrusion **1812**. As described previously, the optical components that are disposed within the cavities that correspond to each of the optical openings **1804**, **1814** may comprise one or more light emitters, one or more light sensors, or a combination of one or more light emitters and one or more light sensors. The cover structures may each include an isolation that extends from the cavity and through the thickness of the cover structure.

In some variations, the underside or back surface of a wearable device may comprise protrusions disposed in the optical path of the light emitter(s) and/or light sensor(s). In such variations, the protrusions may be optically transparent or translucent. For example, the back surface of a wearable device may comprise one or more cavities each having a corresponding optical opening and a protrusion located over each of the optical openings. In some variations, the cover structure disposed over each of the optical openings may be itself a protrusion that applies focal regions of higher pressure directly on the skin regions located under the optical path of the light emitter(s) and/or detector(s). In other words, the skin region(s) that may be subject to increased levels of pressure may co-localize with the illumination field(s) of the one or more light emitters and/or the field-of-view(s) of the one or more light sensors (in contrast to, for example, a protrusion that applies focal regions of increased pressure to skin that is located between the illumination field(s) and/or field-of-view(s) of the emitters and/or detectors, such as is depicted in FIG. **18C**). One variation of a device having an underside or back surface comprising protrusions disposed within the optical path(s) of the light emitter(s) and/or light sensor(s) is depicted in FIGS. **19A-19B**. Back surface **1900** may comprise one or more optical openings or windows **1904** and a convex cover structure or protrusion **1902** disposed over each of the optical openings **1904** of the corresponding cavities. The protrusion **1902** may comprise an optically transparent or translucent material such as acrylic, glass, and the like. FIG. **19B** depicts a side view of the back surface **1900** when the device is worn by an individual and the back surface is located against skin **1908** of the individual. As depicted there, the skin regions located under the protrusion **1902** (which are schematically represented by the arrows in FIG. **19B**) may be subject to increased levels of pressure as compared to the skin regions located under non-protruding portions **1906** of the back surface **1900**. The radius of curvature of the protrusions **1902** may be consistent across the surface of the protrusion (i.e., the curvature of the protrusion approximates the curvature of a sphere), or may vary (i.e., the curvature of the protrusion may be similar to the curvature of an ovoid). As described previously, the optical components that are disposed within each of the cavities that correspond to each of the optical openings **1904** may comprise one or more light emitters, one or more light sensors, or a combination of one or more light emitters and one or more light sensors, as described above. The cover structures may each include an isolation that extends from the cavity and through the thickness of the cover structure.

The height and/or curvature of the one or more protrusions of a back surface of a wearable device may vary, as may be desirable to attain a desired contact and/or pressure profile in the skin of the individual. FIG. **20** depicts

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examples of various protrusion surface geometries of protrusions similar to the protrusions depicted in FIGS. **19A** and **19B** (though such sizes and geometries may be applicable to any of the protrusions and/or optical window cover structures described previously). FIG. **20** depicts an underside or back surface **2000** of a wearable device comprising a protrusion **2002** that is located over an optical opening or window **2004** of a cavity **2006**. In some variations, the protrusion may comprise the cover structure disposed over the optical opening. The protrusion **2002** may have a height **2003** from about 0.3 mm to about 2 mm, for example, about 0.5 mm, or about 0.9 mm, about 1.1 mm, about 1.3 mm, etc. The radius of curvature of the protrusion **2002** may be from about 2.5 mm to about 8.5 mm, for example, about 3.23 mm, about 3.43 mm, about 4.25 mm, about 4.47 mm, about 6.5 mm, about 7.47 mm, etc. The width **2005** of base of the protrusion **2002** may span the width of the optical opening **2004**, or may be less than the width of the optical opening. In some variations, the width **2005** may be from about 3 mm to about 10 mm, for example, about 3.5 mm, about 4.6 mm, about 5.4 mm, about 6 mm, about 7.3 mm, about 8.8 mm, etc.

In some variations, the cover structure and/or protrusion may comprise a Fresnel lens or similar optical component. Since the wearable device may include several optical components and associated wiring, it can be desirable to obscure the components and prevent internal components from being visible to a user's eye. In addition to obscuring the internal components, it may be desirable that the light emitted from a light emitter retains its optical power, collection efficiency, beam shape, and collection area so that the intensity of light is unaffected. To obscure internal components, one or more lenses such as Fresnel lenses may be located in the protrusion, and/or between the protrusion and cover structure, and/or in the cover structure, and/or within the thickness of the housing material, and/or underneath the housing (e.g., within the volume enclosed by the housing). For example, a Fresnel lens **2102** may be located between the protrusion **2100** and a light emitter **2106** that is located within a cavity **2110**, as shown in FIG. **21A**. In this variation, the Fresnel lens **2102** may be located above the optical opening **2104** of the cavity **2110**, that is, extending from the surface **2101** of the device housing **2103**. Fresnel lens **707** can have two regions: an optical center **2109** and a cosmetic zone **2111**. Optical center **2109** can be placed in substantially a same area or location as light emitter **2106** to collimate the emitted light into a smaller beam size. Cosmetic zone **2111** can be located in areas outside of optical center **2109**. The cosmetic zone **2111** may comprise ridges that may help to obscure the underlying internal components. Optionally, a light sensor **2108** disposed within the same cavity **2110** as the light emitter **2106** may be covered by the same or different Fresnel lens, which may or may not have an optical center (i.e., a large-area light sensor may be a large-area photodiode that may not require shaping of the light field may not require a Fresnel lens with an optical center and instead may use a Fresnel lens having one or more regions comprising ridges configured for a cosmetic zone). The ridge shapes of the Fresnel lens **2102** may vary to help facilitate obscuration, especially in cosmetic zones. For example, deep and sharp saw tooth patterns can be used for high obscuration needs. Other types of ridge shapes can include rounded cylindrical ridges, asymmetric shapes, and wavy shapes (i.e., ridges that move in and out). The Fresnel lens **2102** may be used additionally or alternatively for light collimation. By collimating light, the optical signal efficiency can be improved. Without a lens or similar collimat-

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ing optical element, emitter light may be directed at an angle away from the light sensor and can be lost. Additionally or alternatively, light may be directed at an angle toward the light sensor, but the angle may be shallow. The Fresnel lens 2102 may redirect light to directions that otherwise may be lost or enter into the tissue at shallow angles. Such redirected light can be collected instead of being lost and/or may militate against parasitic non-signal light, resulting in improved optical signal efficiency. In some examples, a diffusing agent may be used alternatively or additionally to a Fresnel lens. A diffusing agent may be surrounding, touching, and/or covering one or more components of a light emitter. In some examples, diffusing agent may be a resin or epoxy that encapsulates the dies or components and/or wire bonds. Diffusing agent may be used to adjust the angle of the light emitted from the light emitter. By narrowing the beam of light emitted, more light may be collected by the lens and/or window resulting in a larger amount of detected light by the light sensor.

In another variation depicted in FIG. 21B, a Fresnel lens 2122 may be located between the protrusion 2120 and a light emitter 2126 that is located within a cavity 2130. In this variation, the Fresnel lens 2122 may be located within the optical opening 2124 of the cavity 2130, that is, within the thickness of the device housing 2123. There may optionally be a light sensor 2128 within the cavity 2130. The Fresnel lens 2122 may have any of the characteristics described above, and may or may not have an optical center located over either the light emitter 2126 and/or light sensor 2128 (the variation in FIG. 21B uses a Fresnel lens that does not have an optical center).

As indicated above, some variations of protrusions may comprise an isolation that extends through the entire thickness of the protrusion, where the isolation is configured to separate the light paths of the optical components on one side of the protrusion from the other side. The isolation may extend from within the cavity, through the cavity and through the thickness of the protrusion. FIG. 22A depicts one variation of an underside or back surface 2200 of a wearable device comprising a protrusion 2202 disposed over an optical opening 2204 of a cavity 2206, where the protrusion 2202 comprises an isolation or optical barrier 2203 extending through the thickness of the protrusion. In this example, the isolation 2203 extends from inside the cavity 2206 to and through the protrusion 2202. While the isolation 2203 is depicted as being substantially perpendicular to the base of the cavity, it should be understood that the isolation 2203 may be at an angle with respect to the base of the cavity. A first optical component 2208 (e.g., a light emitter or light sensor) may be located on one side of the cavity and a second optical component 2210 (e.g., a light sensor or a light emitter) may be located on the other side of the cavity such that the isolation 2203 separates the light paths of these first and second optical components within the protrusion and the cavity. Isolation 2203 may be similar to any of the isolation variations described previously. FIG. 22B depicts another variation of an underside or back surface 2220 of a wearable device comprising a protrusion 2222 disposed over an optical opening 2224 of a cavity 2226, where the protrusion 2222 comprises an isolation or optical barrier 2223 extending through the thickness of the protrusion. In this variation, a Fresnel lens assembly 2225 may be located within the optical opening and/or cavity 2226 (e.g., as part of the thickness of the housing and/or located within the volume enclosed by the housing). Alternatively or additionally, a Fresnel lens assembly may be located within the protrusion 2222, as previously described. The Fresnel lens

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assembly 2225 may comprise a first Fresnel lens and a second Fresnel lens that are each coupled to one side of the isolation 2223. The first and second Fresnel lenses may be manufactured as two separate and/or independent Fresnel lenses that are attached to the isolation 2223. Alternatively, the first and second Fresnel lenses may be manufactured as a single Fresnel lens and then cut into two components and attached to the isolation 2223. The one or more Fresnel lenses of a Fresnel lens assembly may have any of the lens characteristics described previously.

In some variations of a wearable device, there may be two or more light emitters in the same cavity and one or more Fresnel lens disposed between the protrusion and the light emitters. The Fresnel lens may comprise one optical center for each light emitter within the cavity. FIG. 22C depicts a wearable device 2230 comprising three light emitters 2232a, b, c located within a cavity 2234, and a Fresnel lens 2236 disposed between the light emitters 2232a, b, c and a cover structure and/or protrusion 2238 located over the opening of the cavity 2234. In this example, there may be a light sensor 2240 disposed in the same cavity of the light emitters and an isolation 2242 that provides an optical barrier between the light sensor and the light emitters. The light emitters 2232a, b, c may be collinearly arranged, or may be offset with respect to each other in any pattern. In some variations, light emitters of a particular wavelength may be located closer to the light sensor than the other light emitters. For example, red and/or infrared light emitters may be in closer proximity to the light sensor than a green light emitter. FIG. 22D is a top view of the cavity 2234 of the device of FIG. 22D. The Fresnel lens 2236 may comprise three optical centers 2237a, b, c that are each located over (e.g., aligned with) a corresponding light emitter 2232a, b, c. The ridge pattern as viewed from above the underside of the device may appear to have three sets of concentric rings, or spirals, or a plurality of concentric and/or merged arcs. In some variations, where the light emitters are not arranged collinearly, the optical centers of the Fresnel lens may be offset with respect to each other. Alternatively, the Fresnel lens may not have any optical centers located over any of the light emitters (and/or light sensors). FIG. 22E depicts an example of a cavity of a wearable device similar to that of FIG. 22D, but where the Fresnel lens does not have an optical center that is located over (e.g., aligned with) a light emitter. The ridge pattern of the Fresnel lens 2250 as viewed from above the underside of the device may appear to have arc-shaped edges. In some variations, a Fresnel lens without any optical centers may have the appearance of a plurality of concentric semicircles, partially truncated circles (e.g., having one, two, three, four or more truncated sides), concentric arcs and the like. The ridge pattern shape, size, edge density, etc. may vary from those depicted in FIGS. 22C and 22D, as may be desirable.

Any number, size, shape/geometry, etc. of the protrusions described above may be applied to any of the devices described herein, as may be desirable.

As discussed above, noise correction can be performed by using a noise reference channel (e.g., including a red or infrared light emitter) to correct or adjust the signal measured by a PPG channel (e.g., including a green light emitter). In some instances, the optical attenuation coefficient associated with the noise reference channel can be smaller than the optical attenuation coefficient associated with the PPG channel. As a result, the light from the noise reference may traverse deeper into the user's tissue compared to the light from the PPG channel, even if the separation distance between the light emitters and light sources are the same. With light traversing deeper, the

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sensing volume in the user's tissue of the noise reference channel may differ from the sensing volume of the PPG channel, thereby possibly reducing the effectiveness of the noise correction. One way to enhance the effectiveness of the noise correction can be to configure the light emitter and light sensor for the noise reference channel to have a shorter separation distance than the light emitter and light sensor for the PPG channel. In some instances, the differing separation distances can result in the optical components occupying a larger area on the back of the device, which can lead to larger windows.

Another way to enhance the effectiveness of the noise correction can be to co-localize the noise reference and PPG channels. FIGS. 23A-23C illustrate cross-sectional views of exemplary configurations of light emitters for co-localizing the noise reference and PPG channels according to examples of the disclosure. In some examples, the light emitters can be configured with different light emission angles, as illustrated in FIG. 23A. Device 2300 can include light emitter 2305, light emitter 2306, and light sensor 2304. Light emitter 2305 and light emitter 2306 can be co-localized such that the separation distance between light emitter 2305 and light sensor 2304 relative to the separation distance between light emitter 2306 and light sensor 2304 can be substantially the same (e.g., within 10% difference). For example, light emitter 2305 can be located in close proximity (e.g., less than or equal to 1 mm away) to light emitter 2306. In some examples, light sensor 2304 can be located in a cavity different from light emitter 2305 and light emitter 2306, separated by isolation 2319. In some examples, one or more light emitter-light sensor sets located in different cavities can be configured to measure pulsatile blood volume changes. In some examples, one or more light emitter-light sensor sets located in the same cavity can be configured to measure non-pulsatile blood volume changes (from shallow tissues structures, deep tissue structures, or both) and/or serve as a noise reference channel. For example, the set comprising light emitter 2306 and light sensor 2304 can be configured to be sensitive to pulsatile blood volume changes. The set comprising light emitter 2305 and light sensor 2304 can be less sensitive to arterial blood volume changes (than the set comprising light emitter 2306 and light sensor 2305) and can be configured to generate a signal indicative of the non-pulsatile blood changes (e.g., noise).

Light emitter 2305 can be configured to emit light towards skin 2320 and in the direction of light sensor 2304, while light emitter 2306 can be configured to emit light towards 2320 and away from the direction of light sensor 2304. In this manner, light emitted by light emitter 2306 can probe deeper into skin 2320, and light emitter by light emitter 2305 can probe shallower into skin 2320. The depth of penetration can be achieved by configuring the angles of light emission from light emitter 2305 and light emitter 2306 to be different, for example. The angles of light emission can be configured such that light from both light emitter 2305 and light emitter 2306 are incident on the same location 2301 and penetrate the same volume of tissue in skin 2320. As a result, device 2300 can include multiple channels configured to measure a similar optical sensing volume even if the attention coefficients of the multiple channels differ and with reduced area constraints. In some variations, the light emitter (e.g., light emitter 2306) included in the PPG channel can be located closer to light sensor 2304 than the light emitter (e.g., light emitter 2305) included in the noise reference channel. Controller 2309 can receive signal 2350 and signal 2355 and can apply one or more algorithms to determine the user's physiological signal. Although the figure illustrates a

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single light ray emitted by the light emitters, examples of the disclosure can include multiple light rays emitted by the light emitters; a single light ray is illustrated for clarity purposes.

In some examples, the device can include one or more reflective walls for changing the depth of penetration of the different light emitters, as illustrated in FIG. 23B. The device can include reflective walls 2315. At least a portion of light emitted by light emitter 2306 can be directed towards light sensor 2304 and can reflect off a reflective wall 2315. A portion of light emitted by light emitter 2305 can be directed away from light sensor 2304 and can reflect off a reflective wall 2315. Both light rays can be incident on the same location 2301 and/or same volume of tissue in skin 2320.

In some examples, the device can include one or more Fresnel lenses for changing the angles of light emitted by the light emitters, as illustrated in FIG. 23C. The device can include Fresnel lens 2322. In some examples, light emitted by light emitter 2305 and light emitter 2306 can include the same angle of incidence on the surface of Fresnel lens 2322. The Fresnel lens can be configured to change the angle of incidences of the light beams. For example, Fresnel lens 2322 can redirect light emitted by emitter 2306 towards one direction and can redirect light emitted by light emitter 2306 towards another direction. In some examples, the angles of light exiting Fresnel lens 2322 can be between 30-60°. The angles for light originating from light emitter 2306 can be the same or different from light originating from light emitter 2305. Both light rays can be incident on the same location 2301 and/or same volume of tissue in skin 2320.

Although the disclosed examples have been fully described with reference to the accompanying drawings, it is to be noted that various changes and modifications will become apparent to those skilled in the art. Such changes and modifications are to be understood as being included within the scope of the disclosed examples as defined by the appended claims.

What is claimed is:

1. A method for determining a physiological signal, the method comprising:
  - emitting a first light at a user;
  - detecting a first reflection of the first light;
  - generating a first signal indicative of the detected first reflection of the first light, the first signal including non-pulsatile blood information;
  - detecting an acceleration of the user;
  - generating a second signal indicative of the acceleration;
  - comparing the second signal to a threshold value;
  - in response to the second signal being greater than or equal to the threshold value, emitting a second light at the user;
  - detecting a second reflection of the second light;
  - generating a third signal indicative of the detected second reflection of the second light, the third signal including pulsatile blood information;
  - adjusting the third signal to compensate for information included in the first signal; and
  - determining the physiological signal based on the adjusted third signal.
2. The method of claim 1, wherein the first light is emitted at a first portion of the user and the second light is emitted at a second portion, different from the first portion, of the user.
3. The method of claim 1, further comprising:
  - determining one or more peaks included in the first and third signals; and

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determining one or more locations of the one or more peaks, wherein adjusting the third signal includes scaling the third signal at the one or more locations.

4. The method of claim 1, wherein adjusting the third signal further includes using information included in the second signal.

5. An electronic device comprising:  
a housing at least partially defining a first cavity and a second cavity separate from the first cavity;  
a first light emitter positioned in the first cavity and configured to generate a first light;  
a first light sensor positioned in the first cavity and configured to:

detect a first reflection of the first light; and  
generate a first signal indicative of the first reflection of the first light, the first signal including non-pulsatile blood information;

a second light emitter positioned in the first cavity and configured to generate a second light;

a second light sensor positioned in the second cavity and configured to:

detect a second reflection of the second light; and  
generate a second signal indicative of the second reflection of the second light, the second signal including pulsatile blood information; and

a controller coupled to the first light sensor and the second light sensor, the controller configured to:

receive the first signal and the second signal; and  
determine at least a portion of a physiological signal using the first signal and the second signal.

6. The electronic device of claim 5, further comprising an isolation member positioned at least partially within the housing and configured to separate the first cavity and the second cavity.

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7. The electronic device of claim 5, further comprising an isolation member positioned between the first light emitter and the first light sensor and configured to optically isolate the first light emitter and the first light sensor.

8. The electronic device of claim 7, wherein:  
the electronic device further comprises a window optically coupled to the first light emitter; and  
an end of the isolation member extends to an inner surface of the window.

9. The electronic device of claim 7, wherein:  
the electronic device further comprises a window optically coupled to the first light emitter; and  
an end of the isolation member extends to an outer surface of the window.

10. The electronic device of claim 5, wherein the first light emitter is spaced less than 1 mm from the first light sensor.

11. The electronic device of claim 5, wherein:  
the electronic device further comprises one or more third light emitters configured to generate a third light;  
at least one of the first light sensor or the second light sensor is, further configured to:  
detect a third reflection of the third light; and  
generate a third signal indicative of the third reflection of the third light; and

the controller is further configured to receive the third signal and include the third signal in the determination of the physiological signal.

12. The electronic device of claim 11, wherein the first light includes light with a wavelength between 570-750 nm, the second light includes light with a wavelength between 495-570 nm, and the third light includes light with a wavelength between 750-1400 nm.

\* \* \* \* \*



US 20100030040A1

(19) **United States**(12) **Patent Application Publication****Poeze et al.**(10) **Pub. No.: US 2010/0030040 A1**(43) **Pub. Date: Feb. 4, 2010**

(54) **MULTI-STREAM DATA COLLECTION  
SYSTEM FOR NONINVASIVE  
MEASUREMENT OF BLOOD  
CONSTITUENTS**

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(21) Appl. No.: **12/534,827**

(22) Filed: **Aug. 3, 2009**

**Related U.S. Application Data**

(60) Provisional application No. 61/086,060, filed on Aug. 4, 2008, provisional application No. 61/086,108, filed on Aug. 4, 2008, provisional application No. 61/086,063, filed on Aug. 4, 2008, provisional application No. 61/086,057, filed on Aug. 4, 2008, provisional application No. 61/091,732, filed on Aug. 25, 2008.

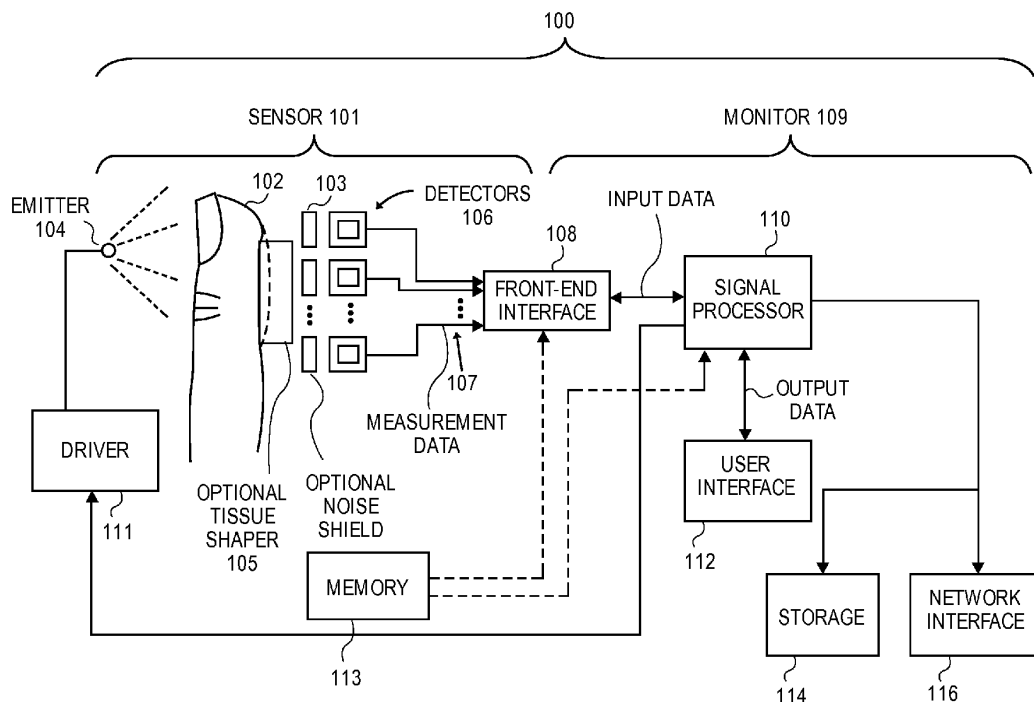
**Publication Classification**

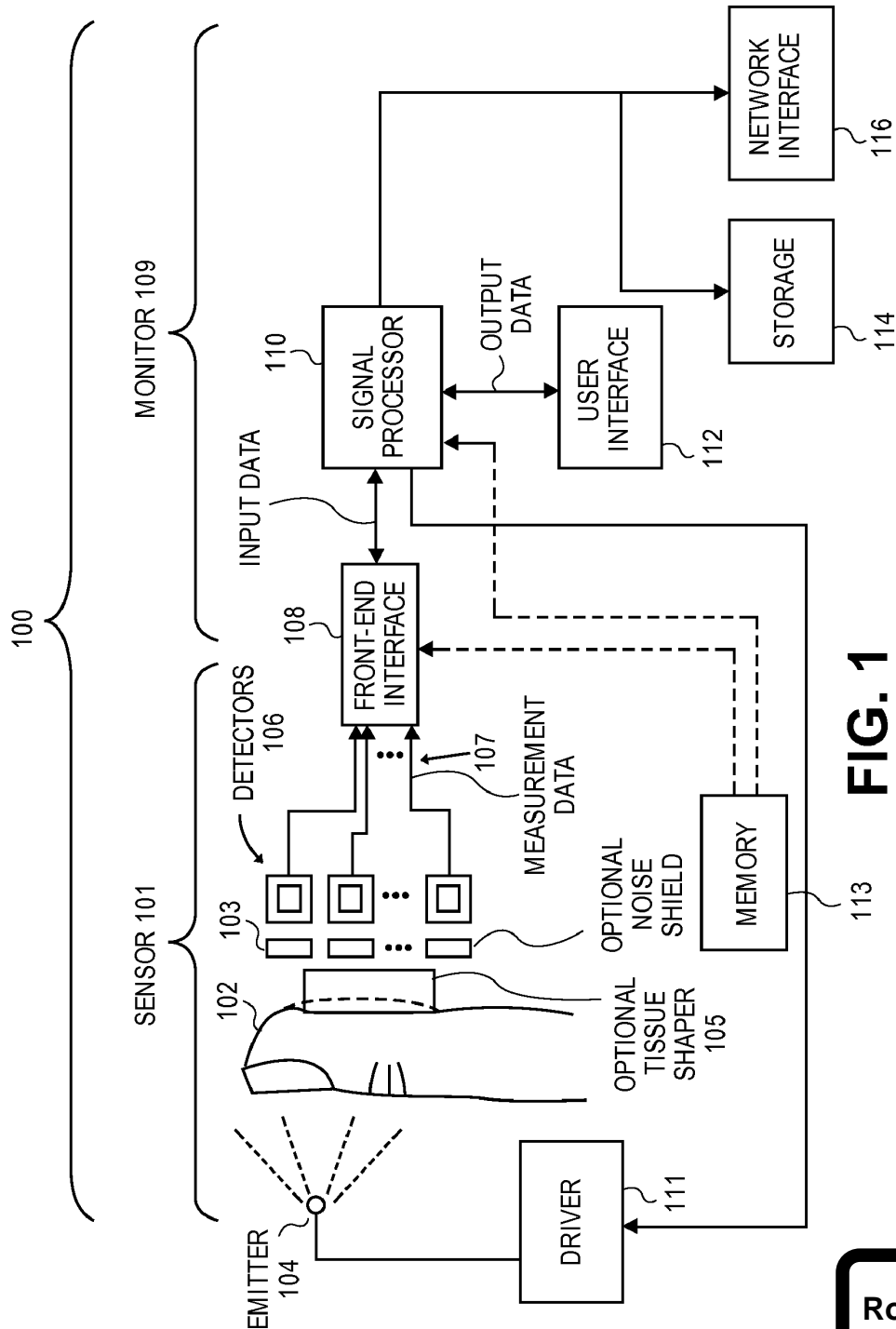
(51) **Int. Cl.**  
**A61B 5/1455** (2006.01)

(52) **U.S. Cl.** ..... **600/316**

(57) **ABSTRACT**

The present disclosure relates to noninvasive methods, devices, and systems for measuring various blood constituents or analytes, such as glucose. In an embodiment, a light source comprises LEDs and super-luminescent LEDs. The light source emits light at least wavelengths of about 1610 nm, about 1640 nm, and about 1665 nm. In an embodiment, the detector comprises a plurality of photodetectors arranged in a special geometry comprising one of a substantially linear substantially equal spaced geometry, a substantially linear substantially non-equal spaced geometry, and a substantially grid geometry.

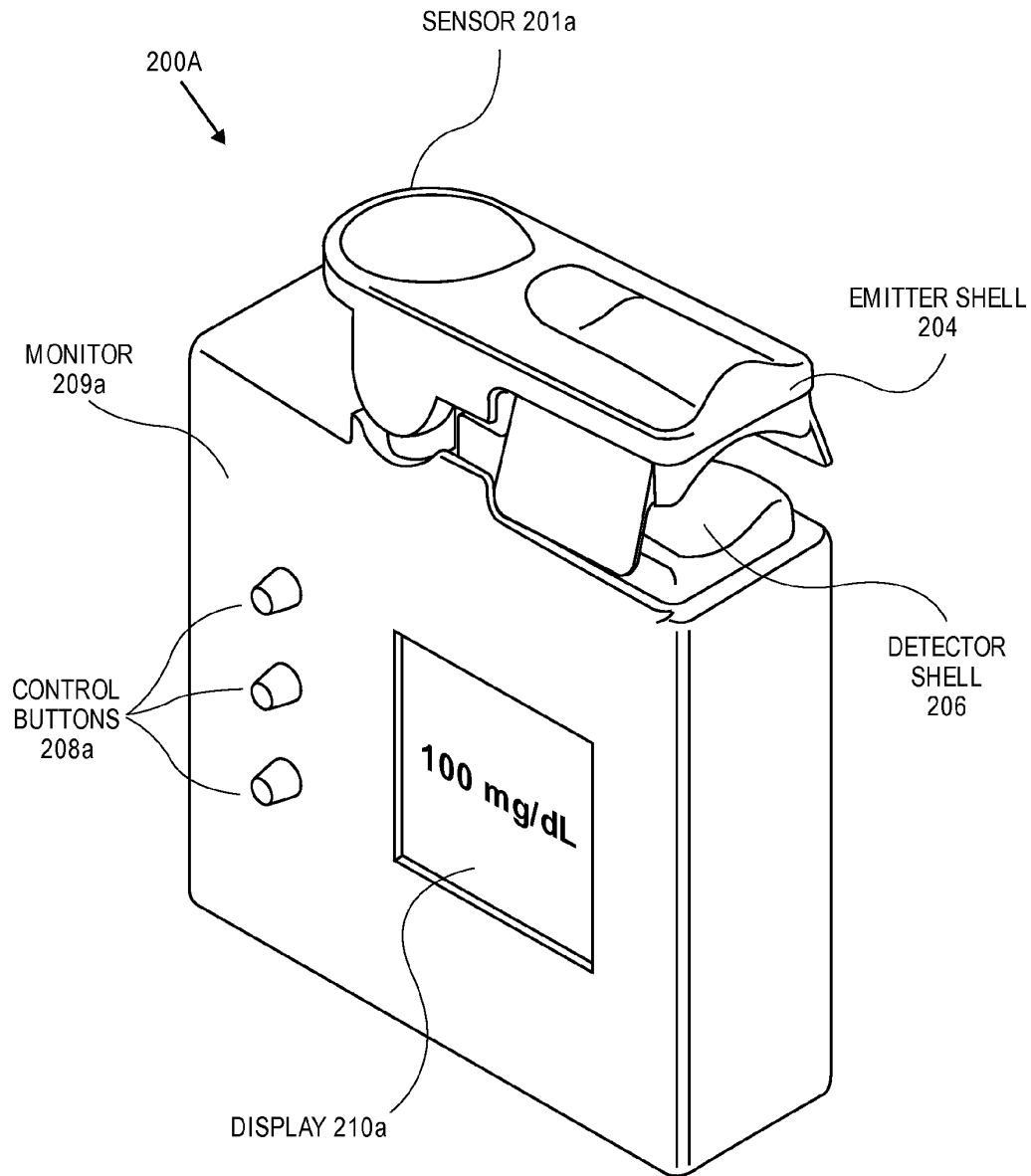




**FIG. 1**

**Rollins Exhibit  
137 (2-23-22)**

WWW.DIGITALEVIDENCEGROUP.COM



**FIG. 2A**

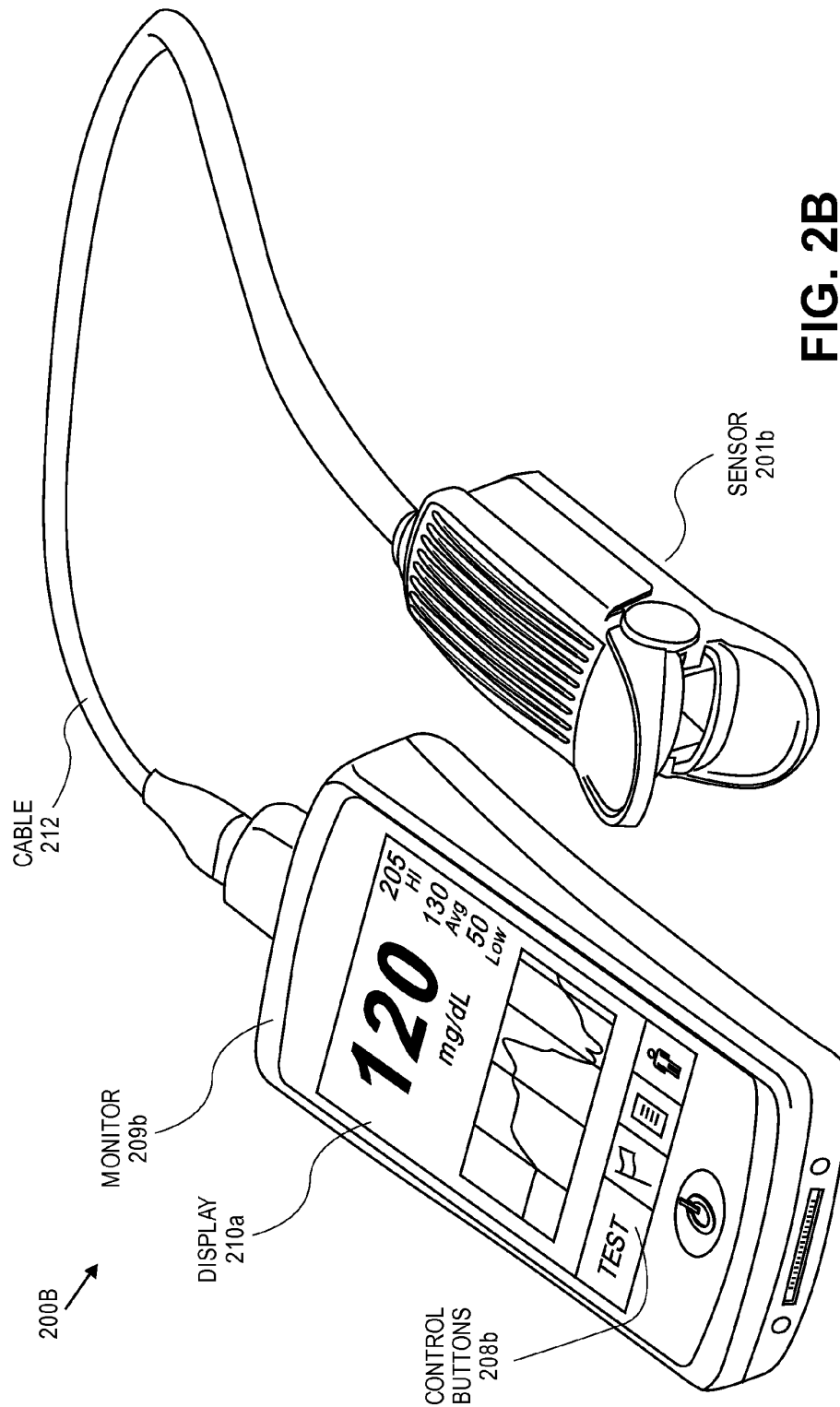
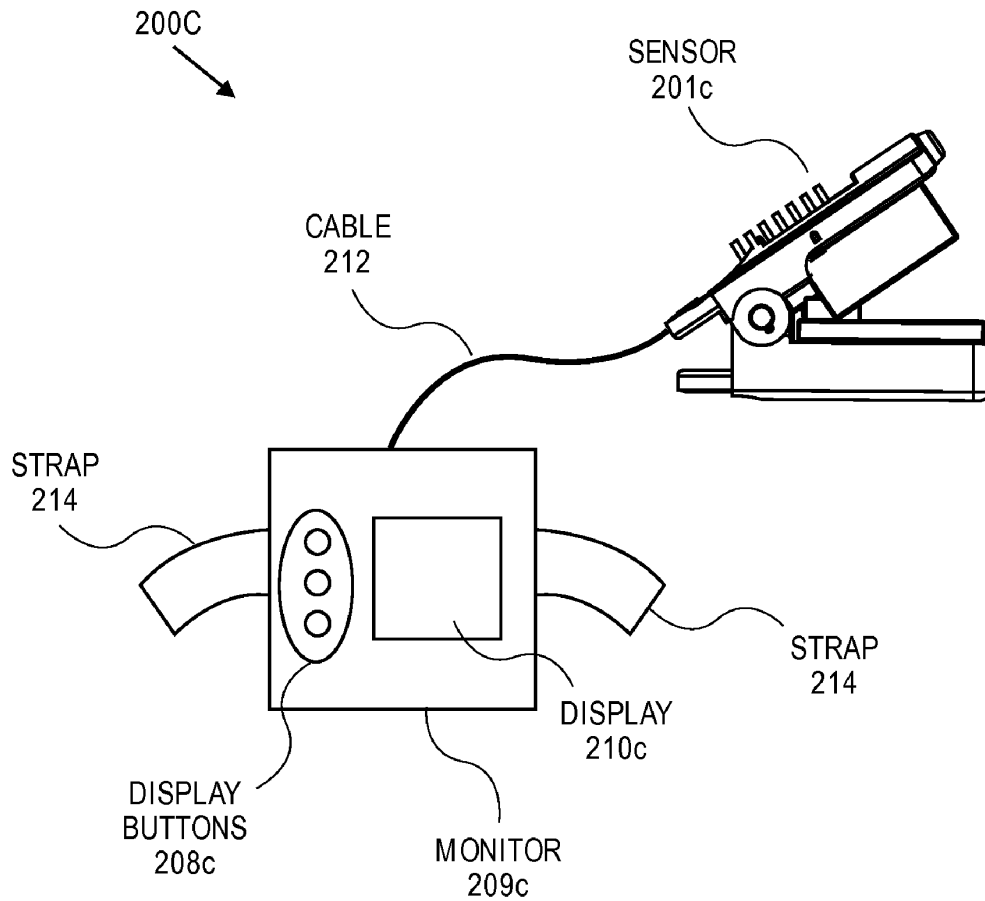
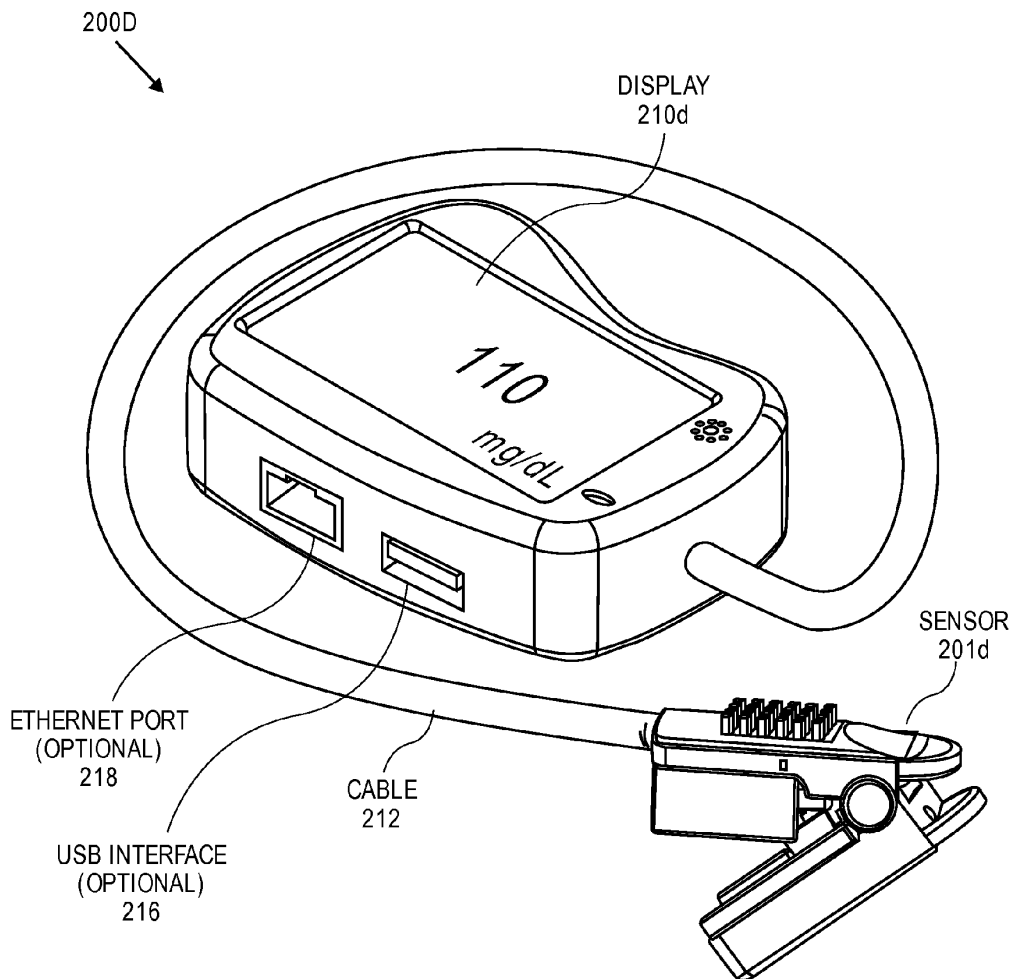


FIG. 2B





**FIG. 2C**



**FIG. 2D**

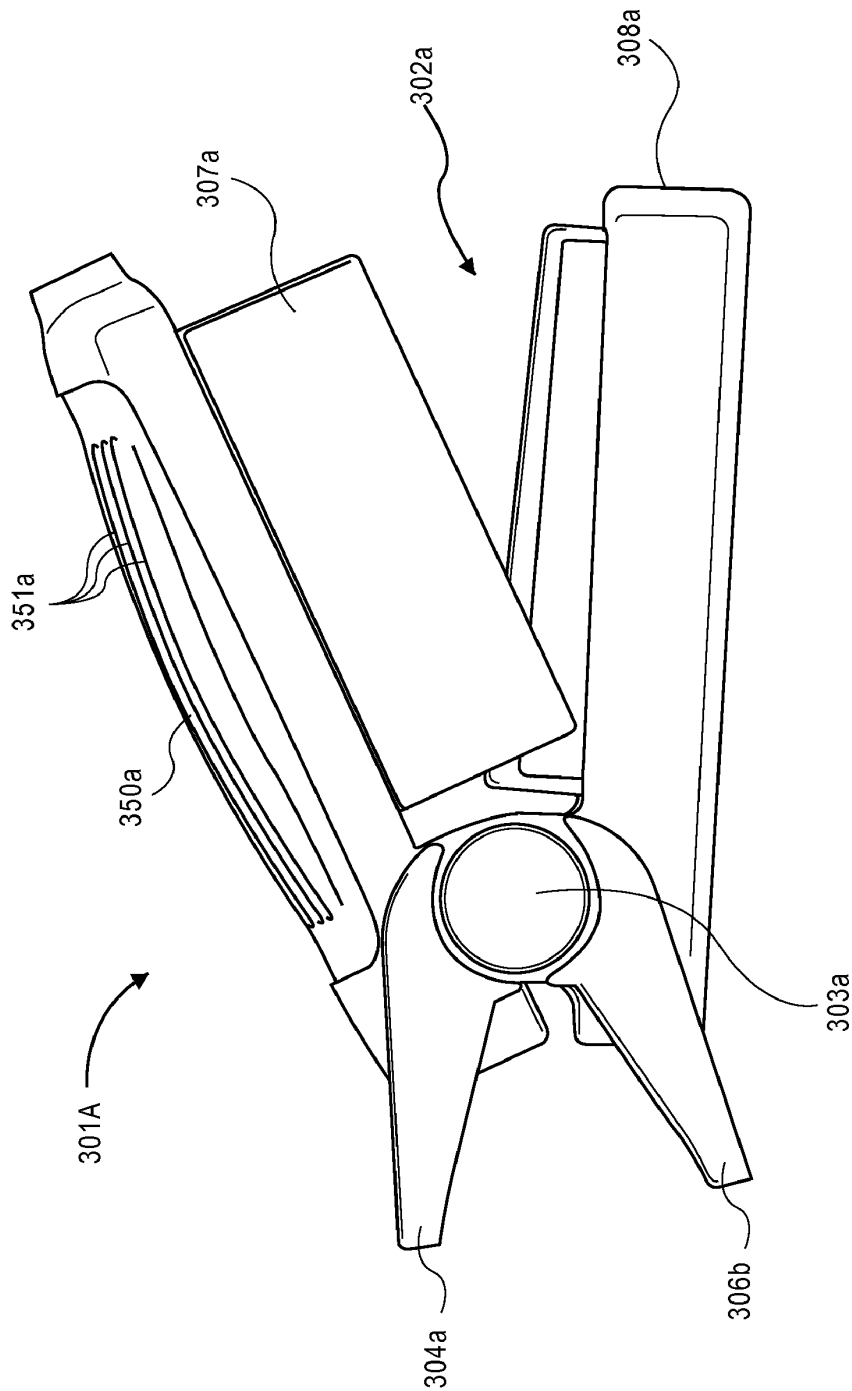
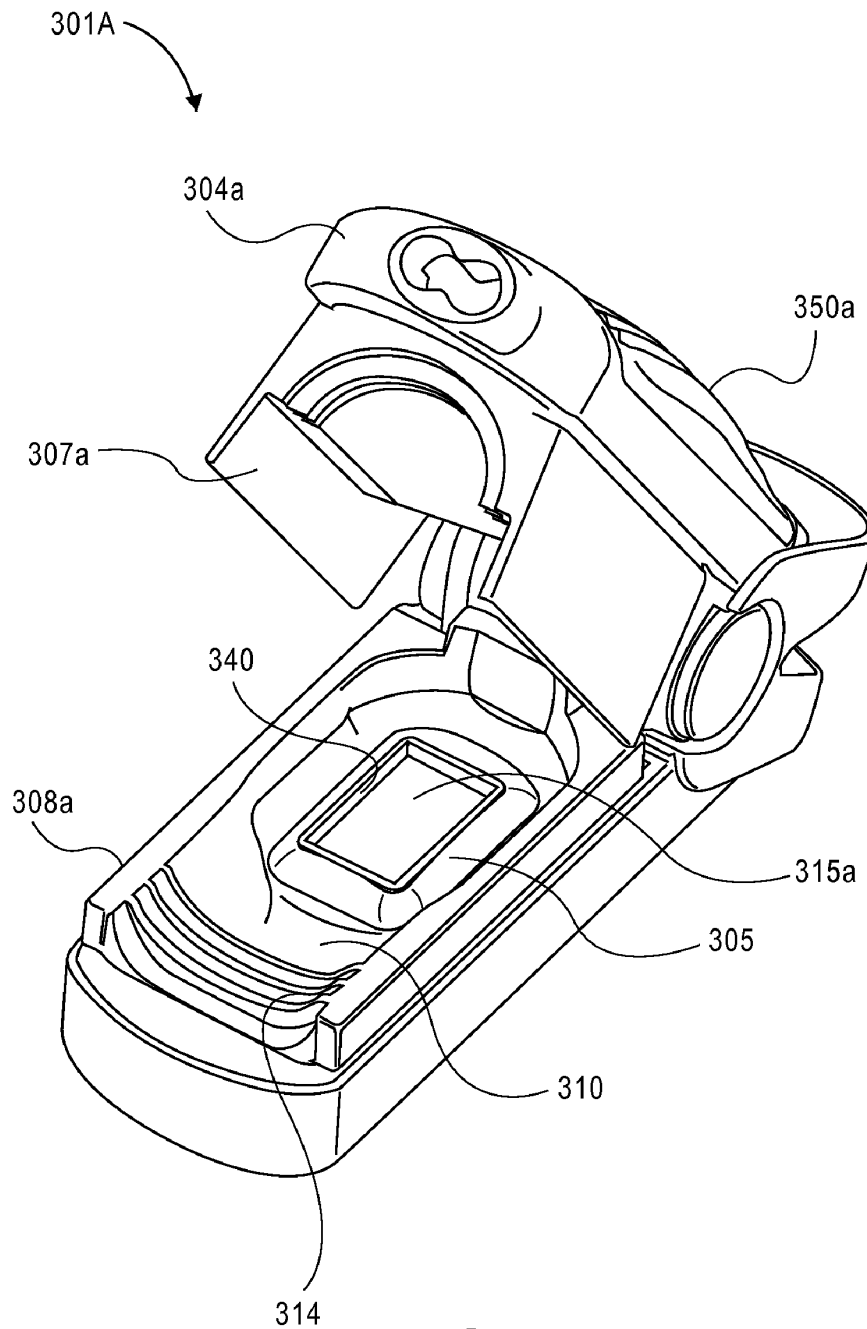
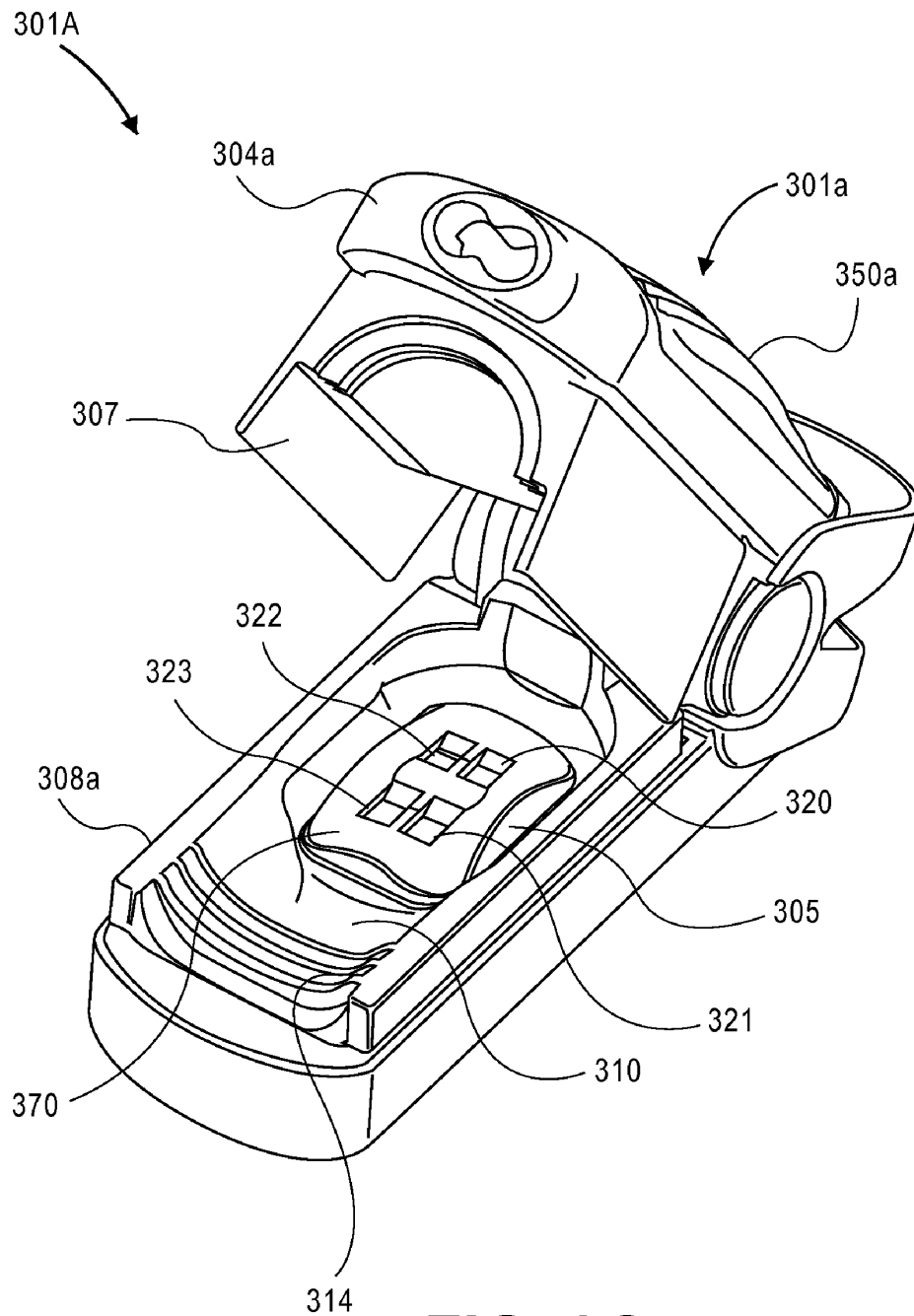


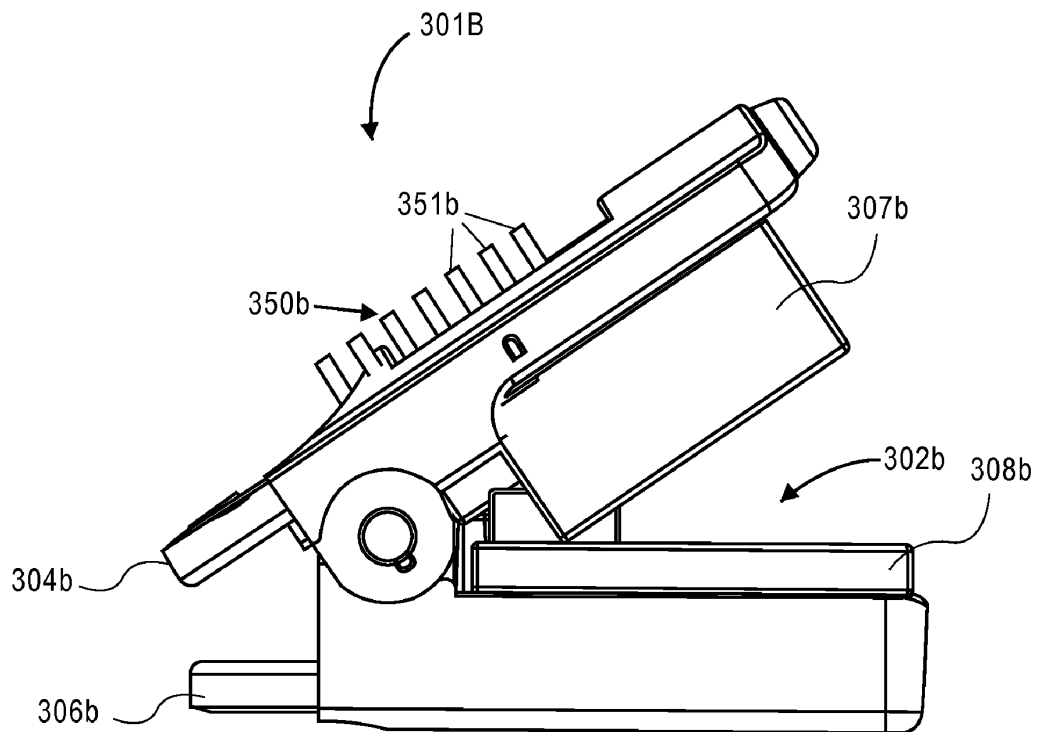
FIG. 3A



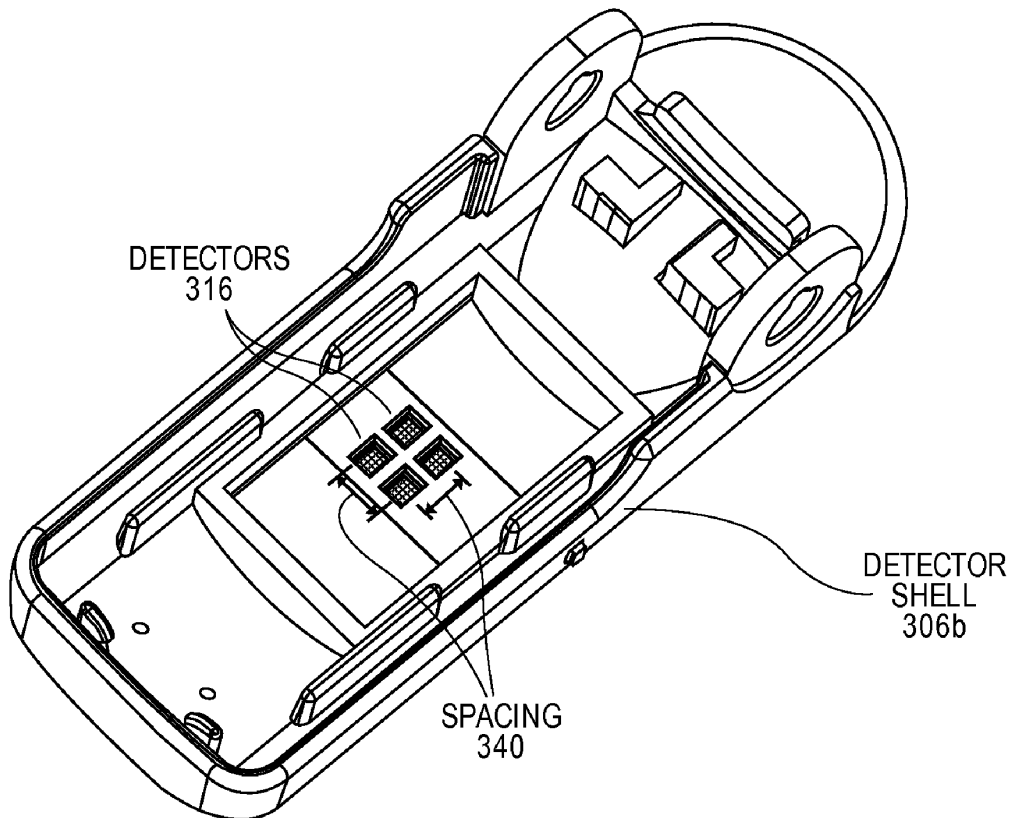
**FIG. 3B**



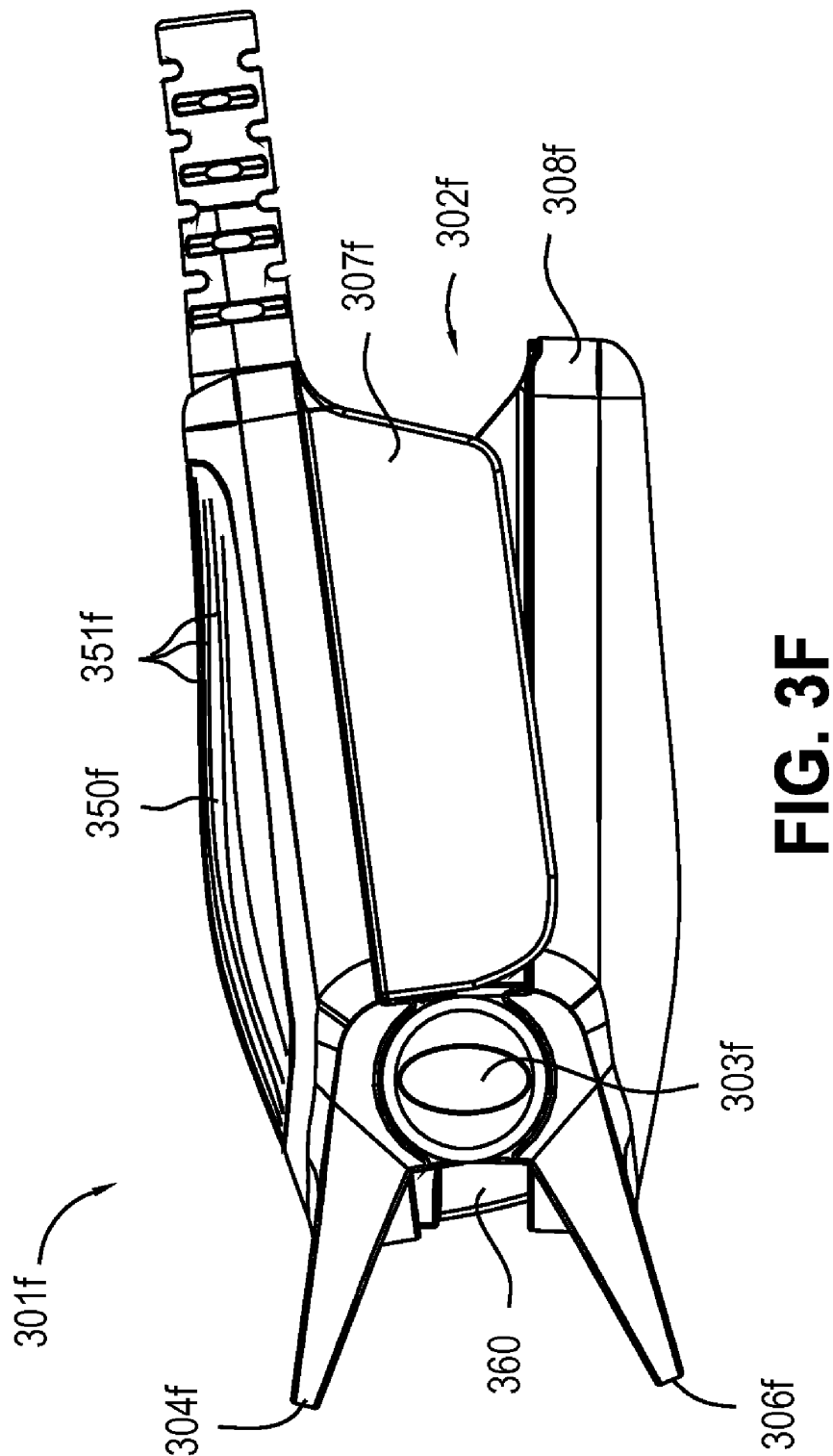
**FIG. 3C**



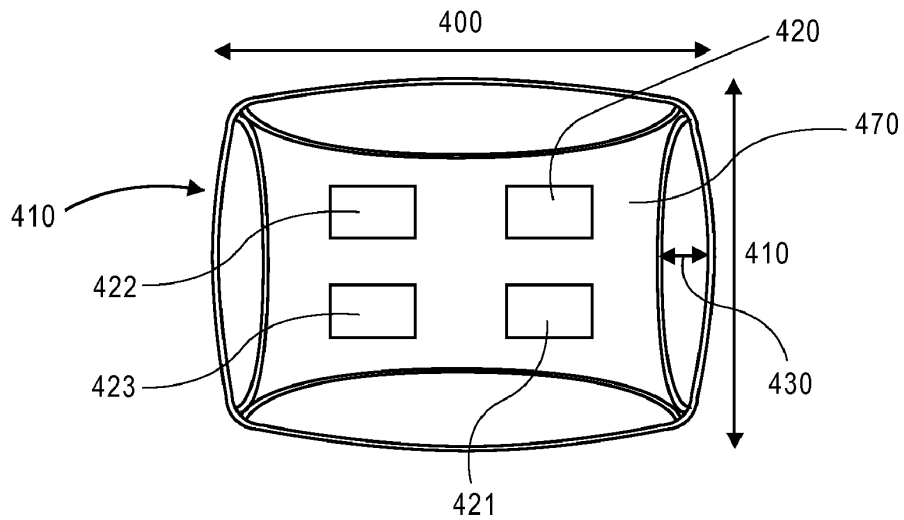
**FIG. 3D**



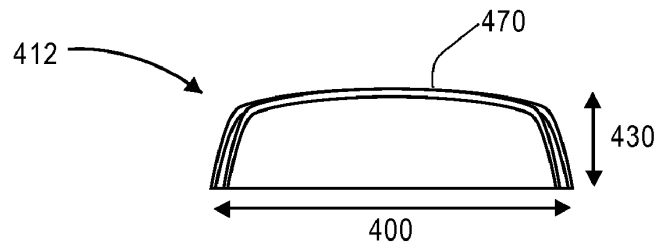
**FIG. 3E**



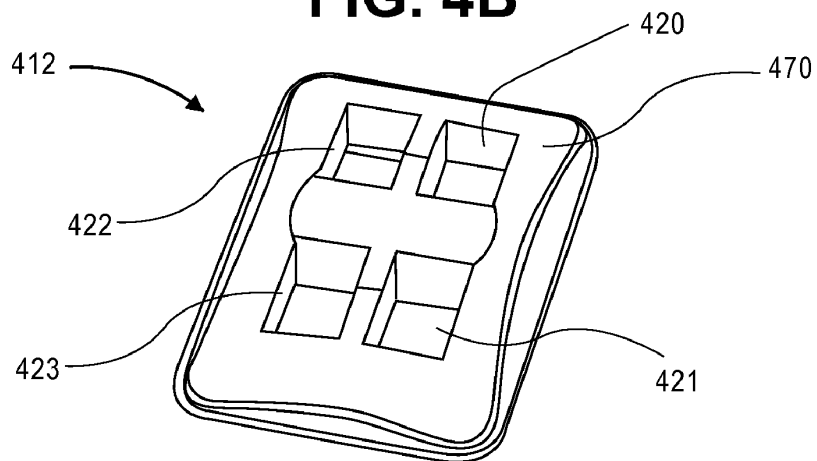




**FIG. 4A**



**FIG. 4B**



**FIG. 4C**

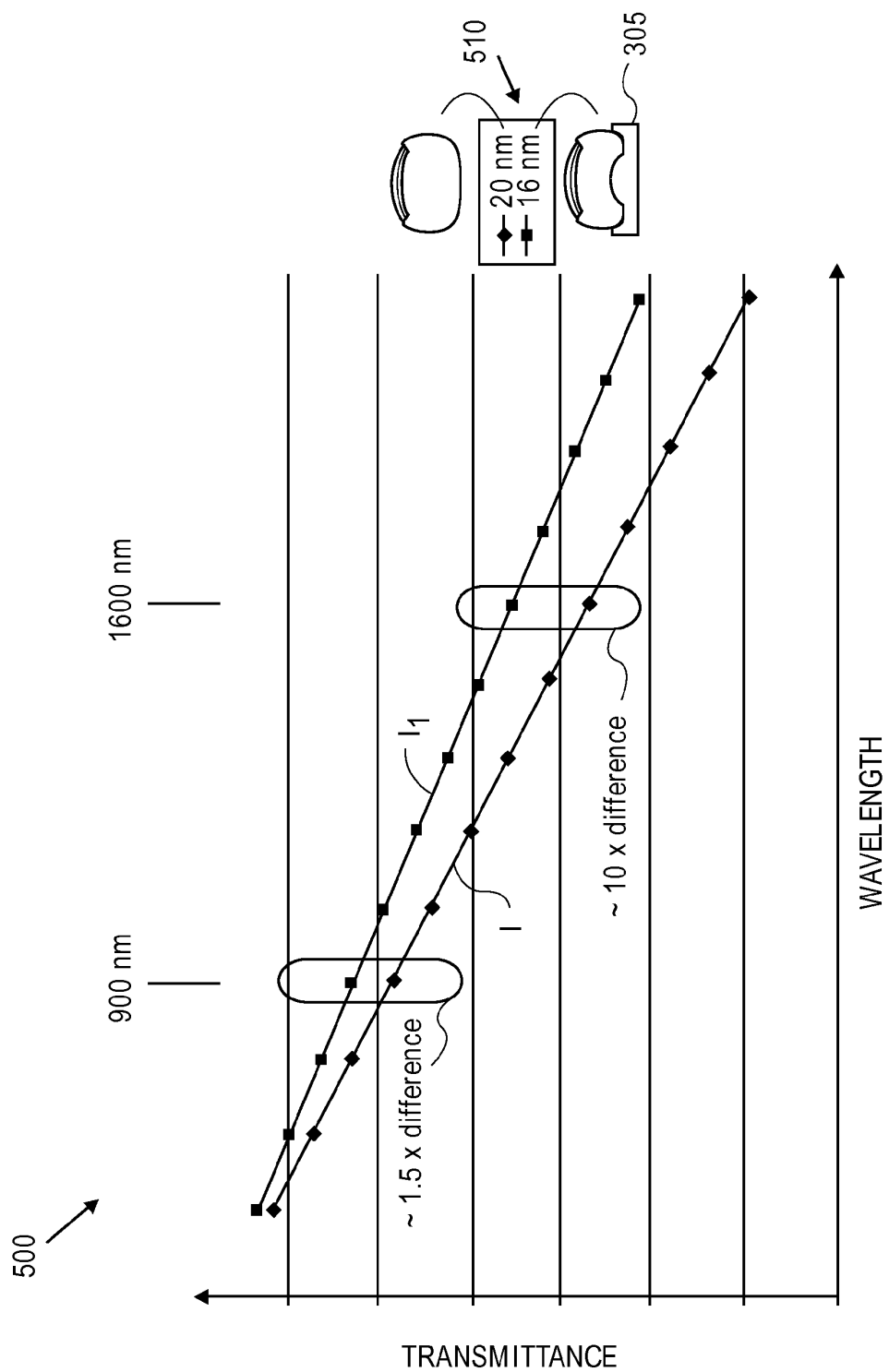
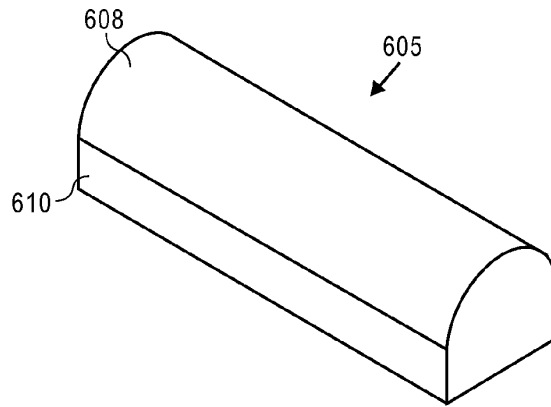
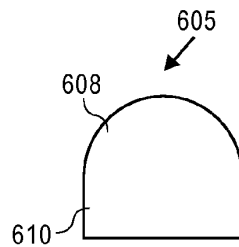


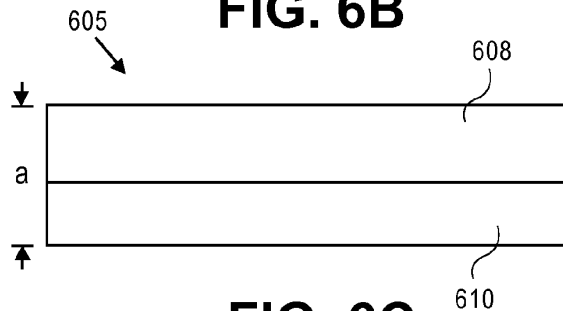
FIG. 5



**FIG. 6A**



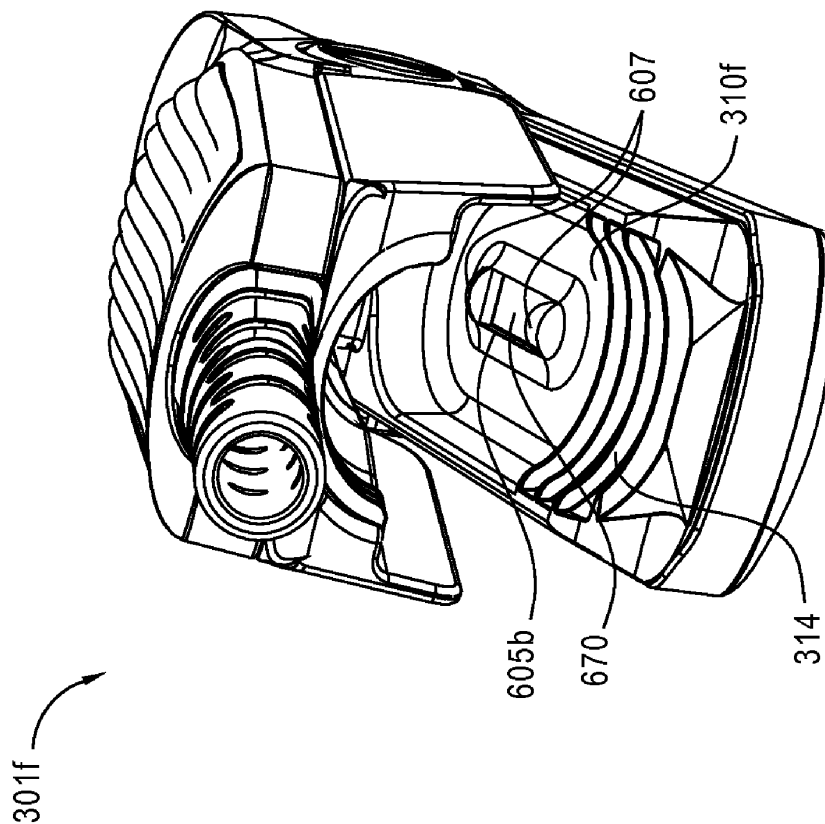
**FIG. 6B**



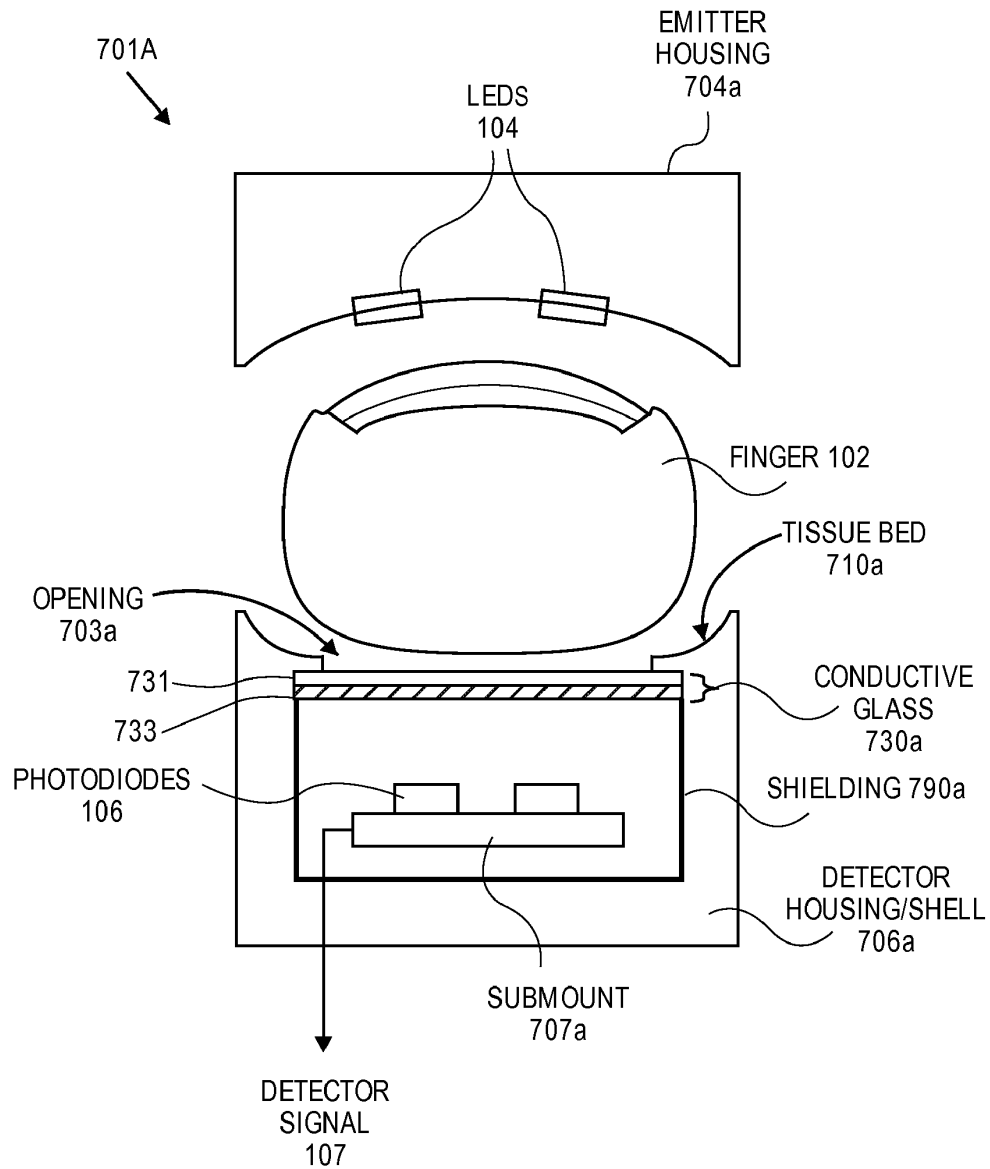
**FIG. 6C**

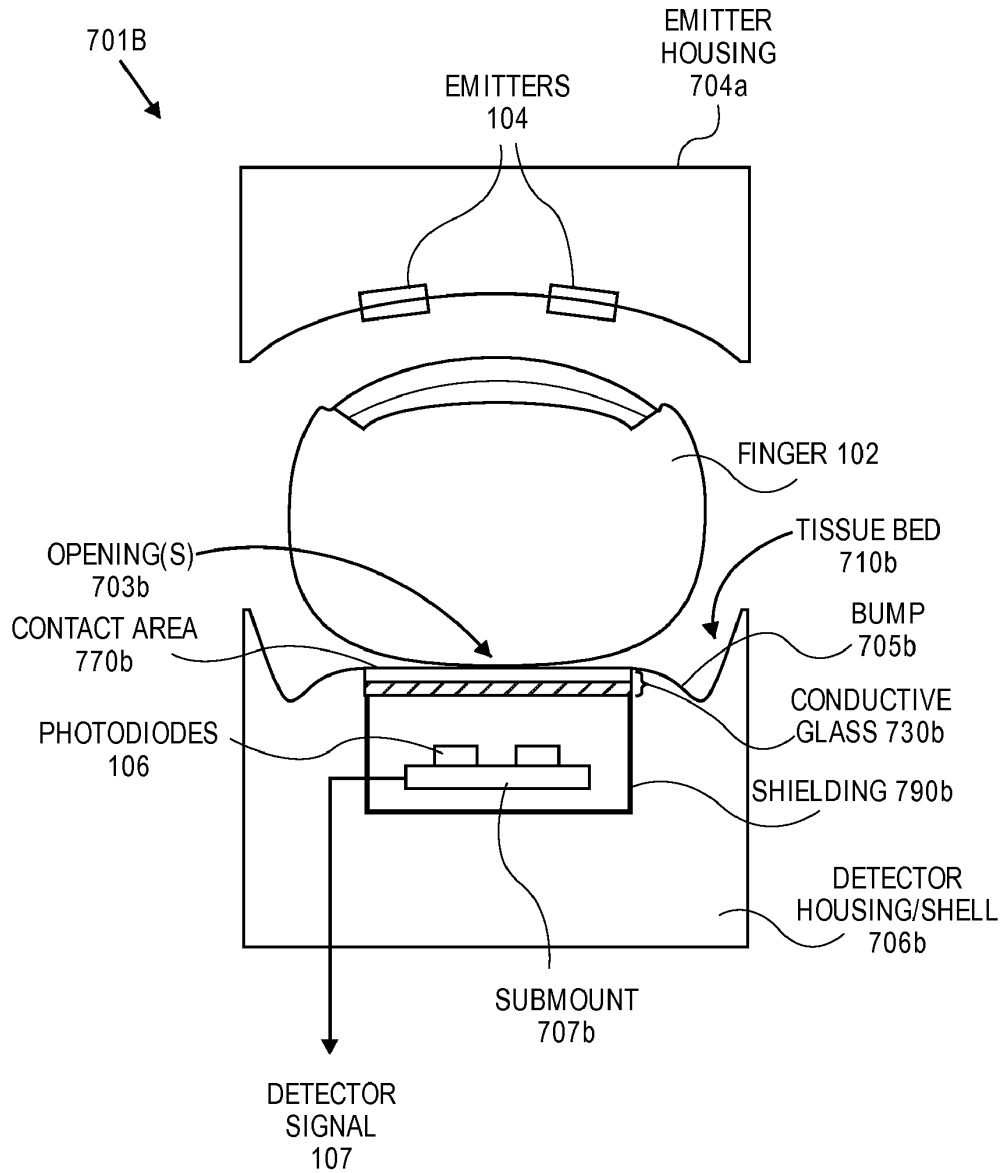


**FIG. 6D**

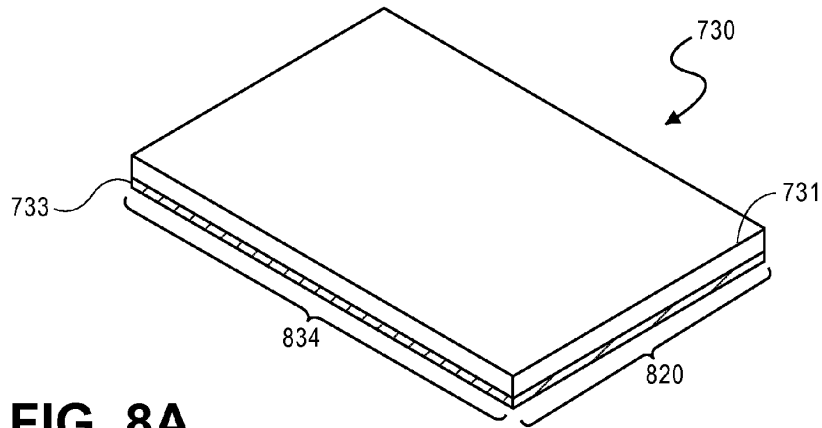


**FIG. 6E**

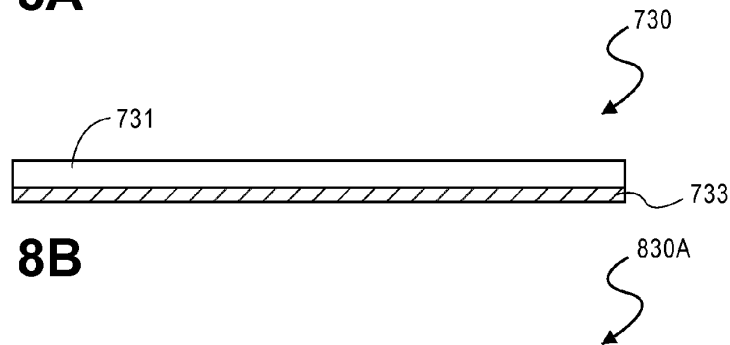
**FIG. 7A**



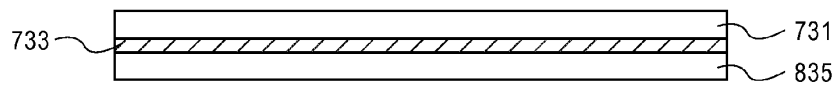
**FIG. 7B**



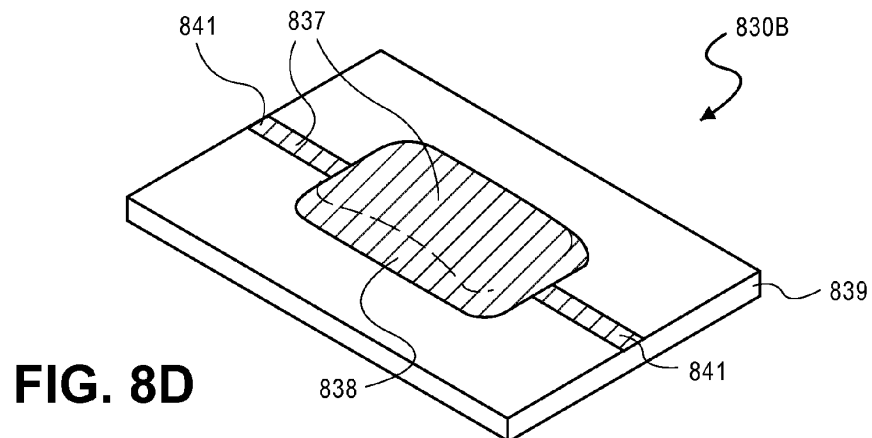
**FIG. 8A**



**FIG. 8B**



**FIG. 8C**



**FIG. 8D**

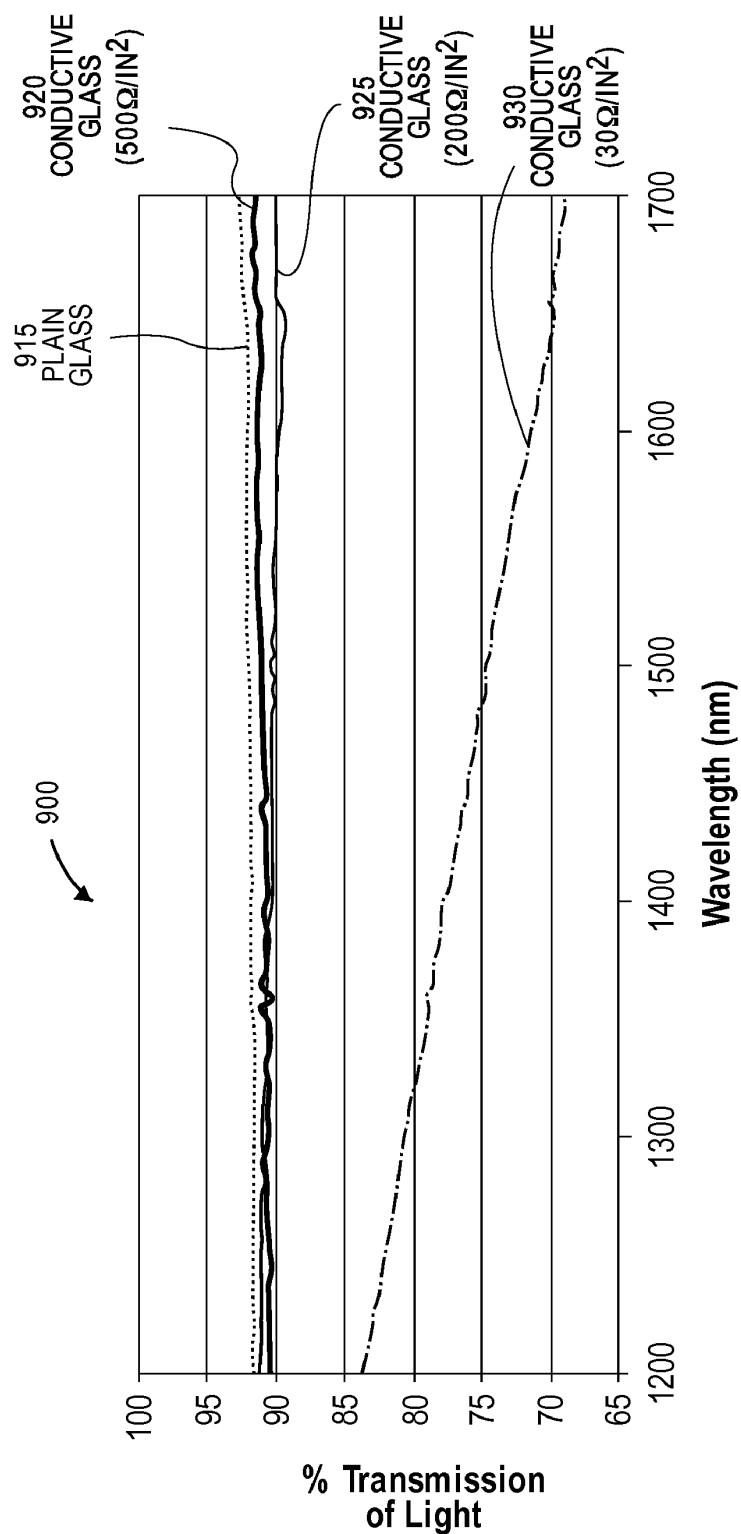
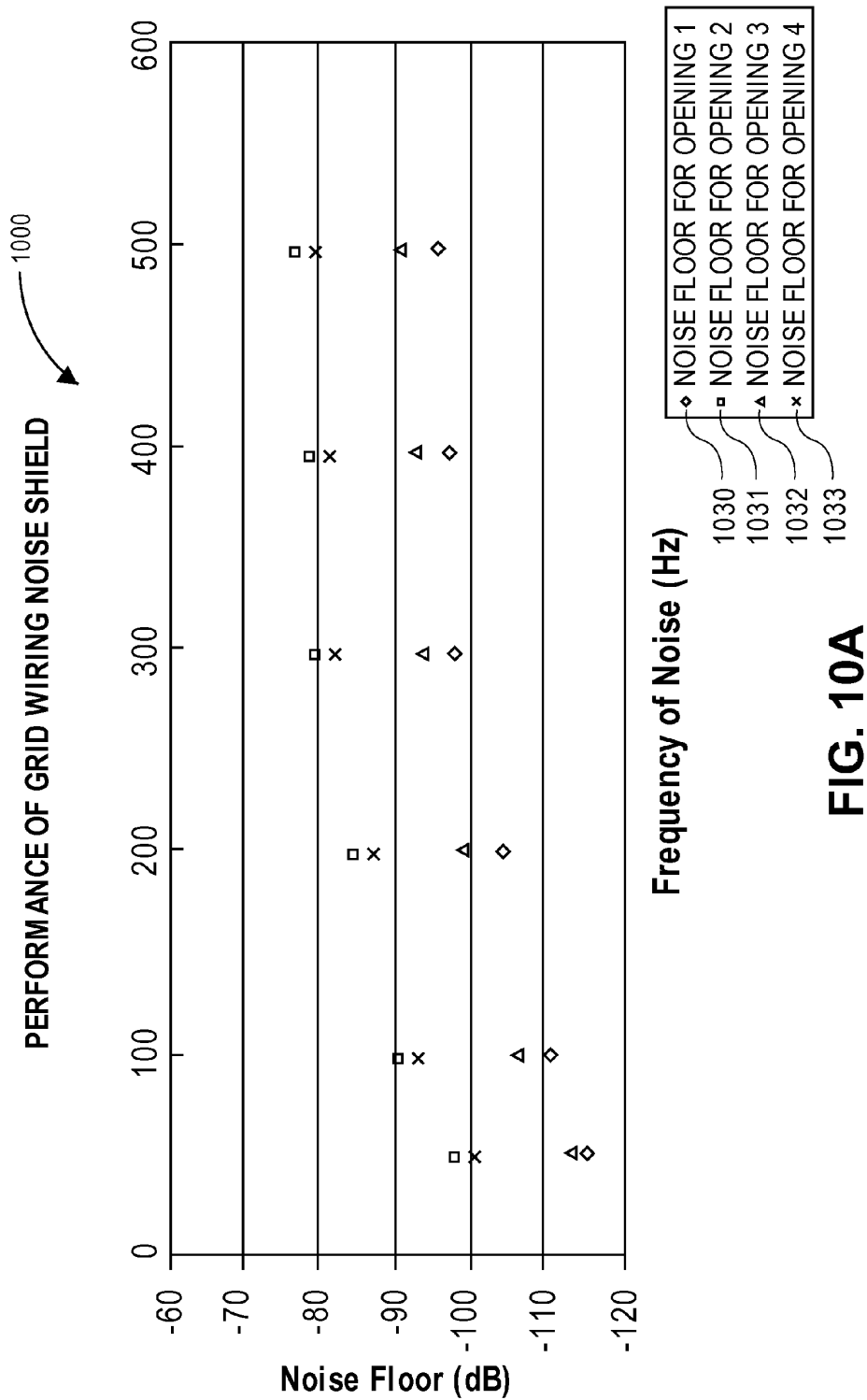
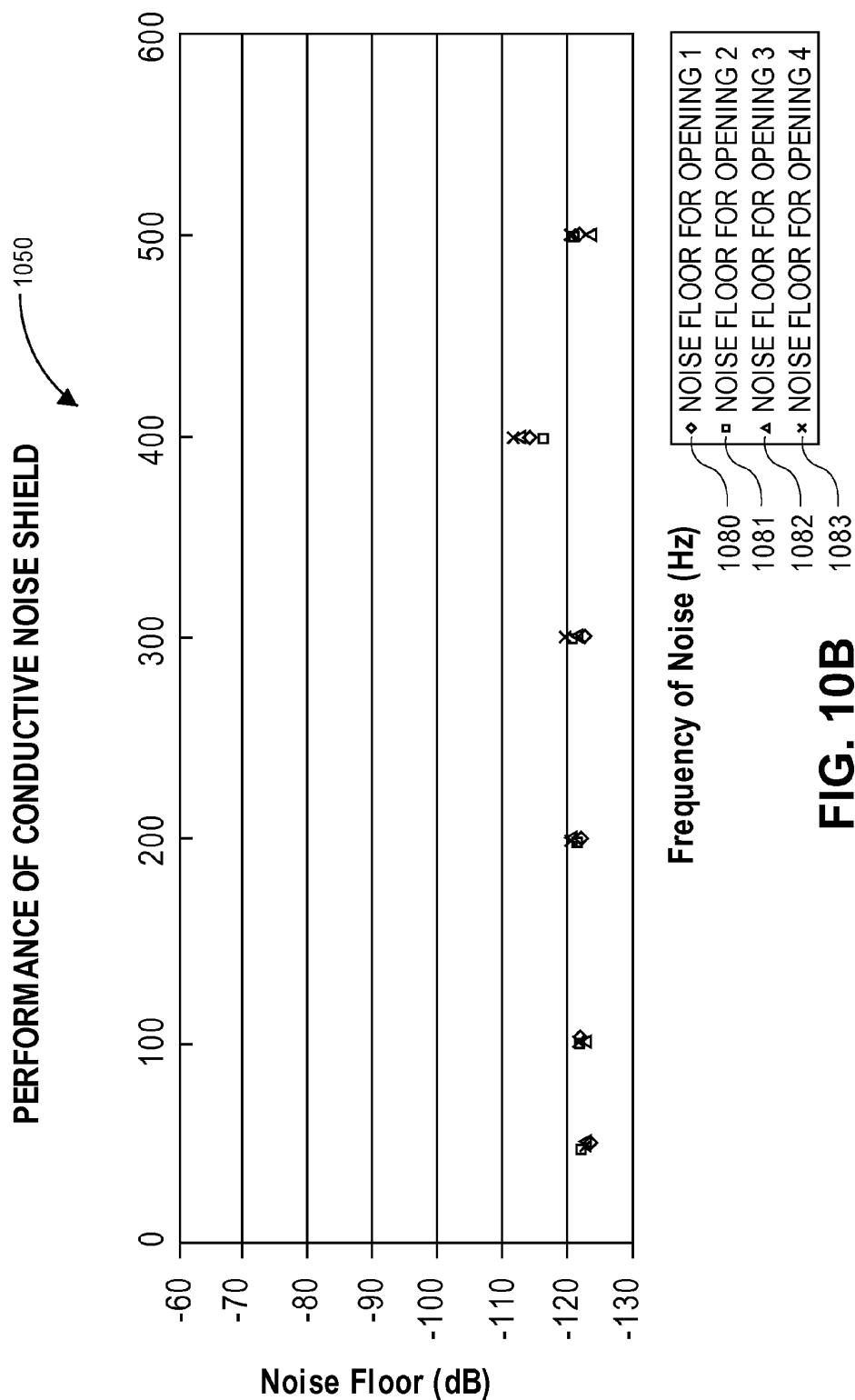


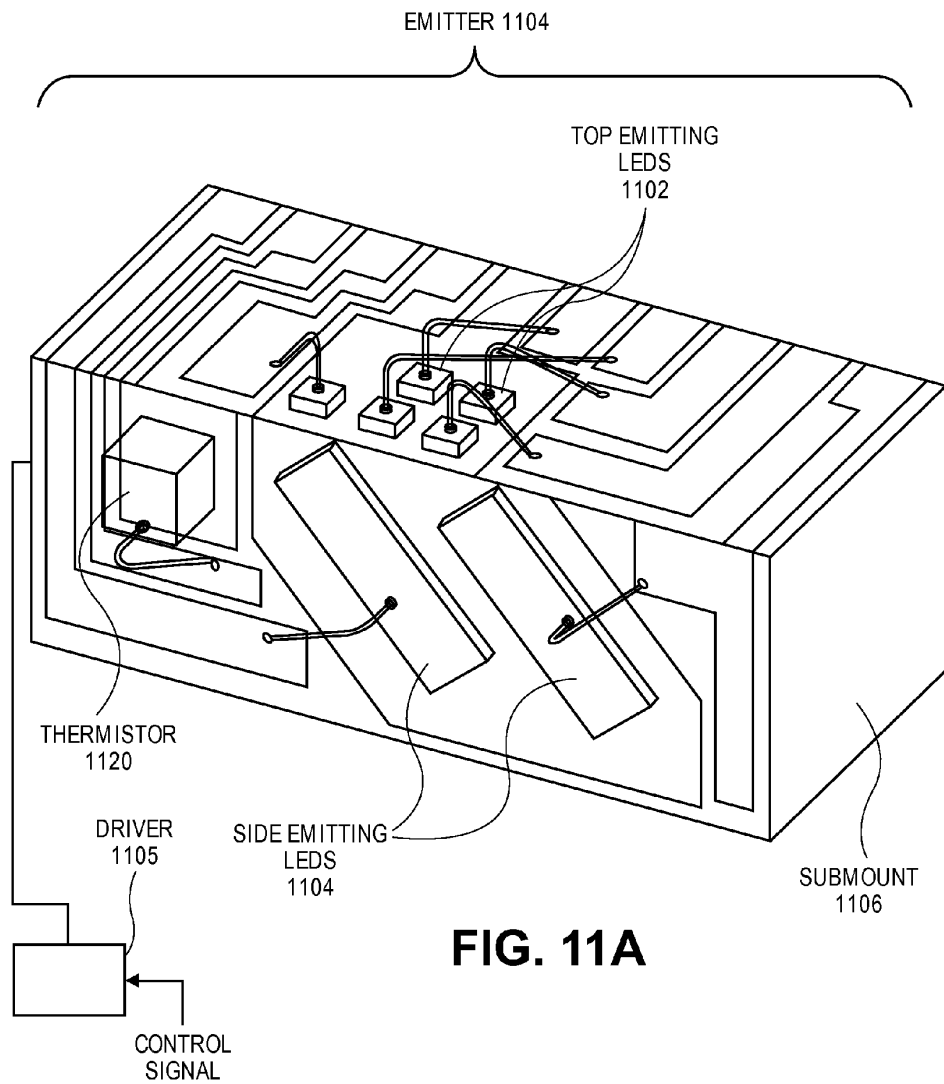
FIG. 9

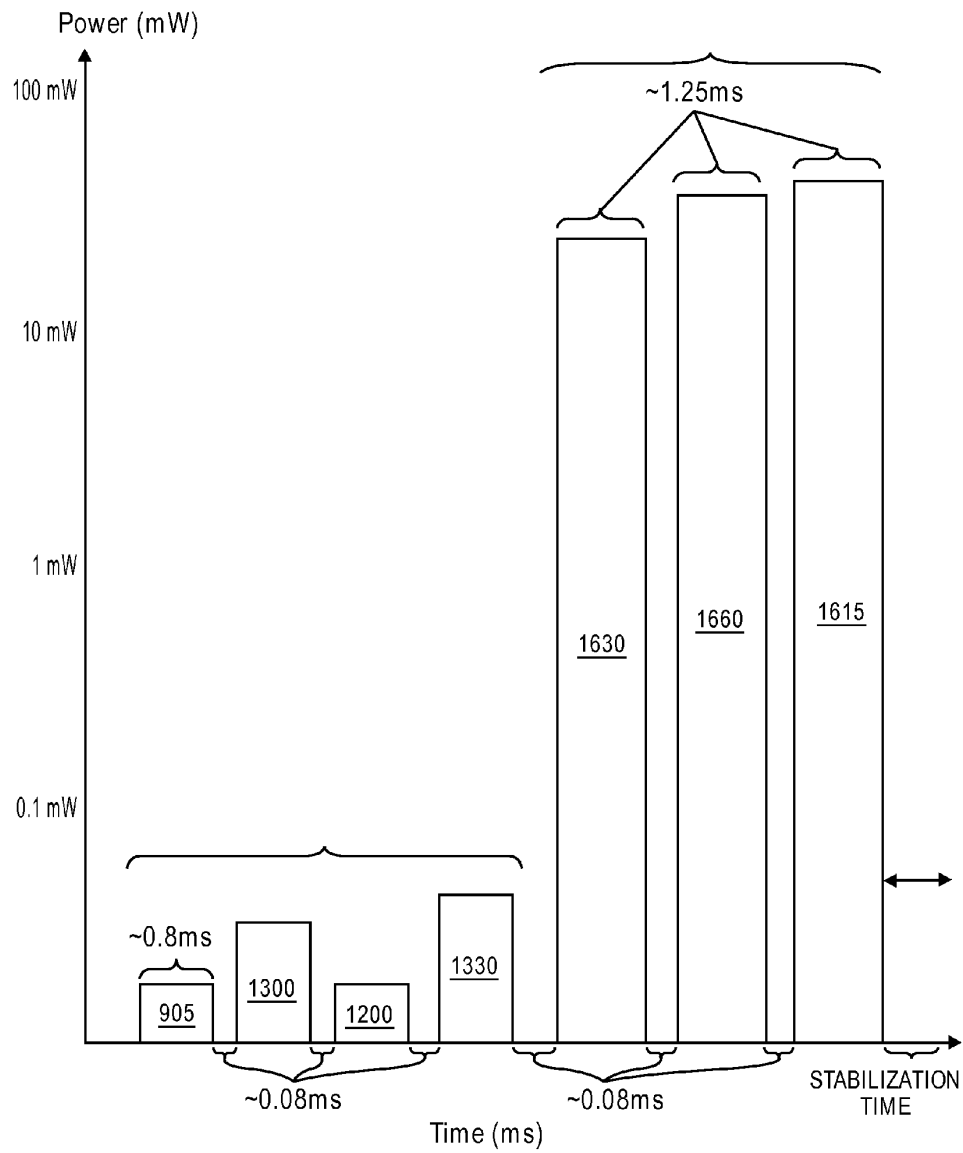




**FIG. 10A**





**FIG. 11B**

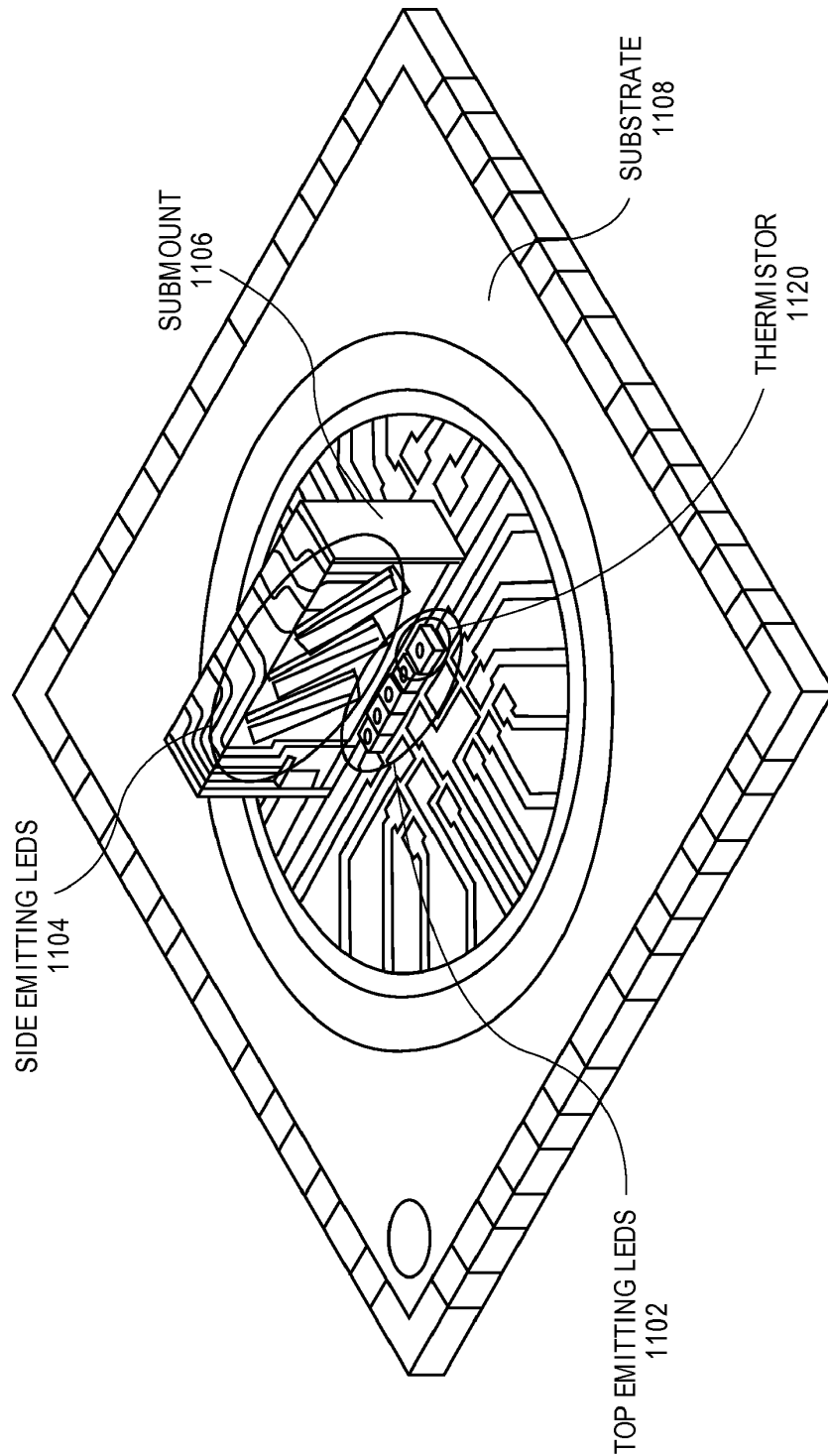


FIG. 11C

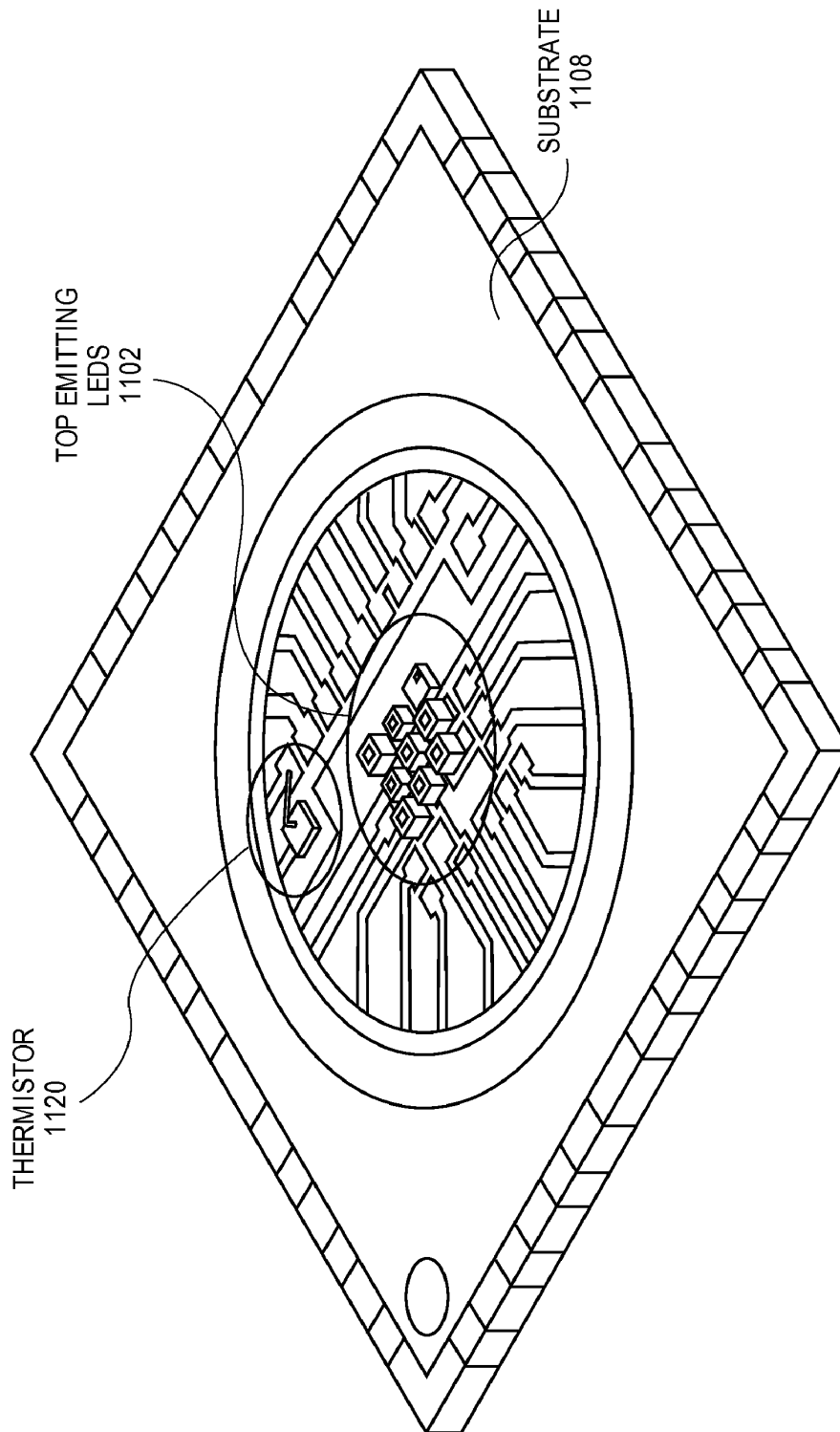
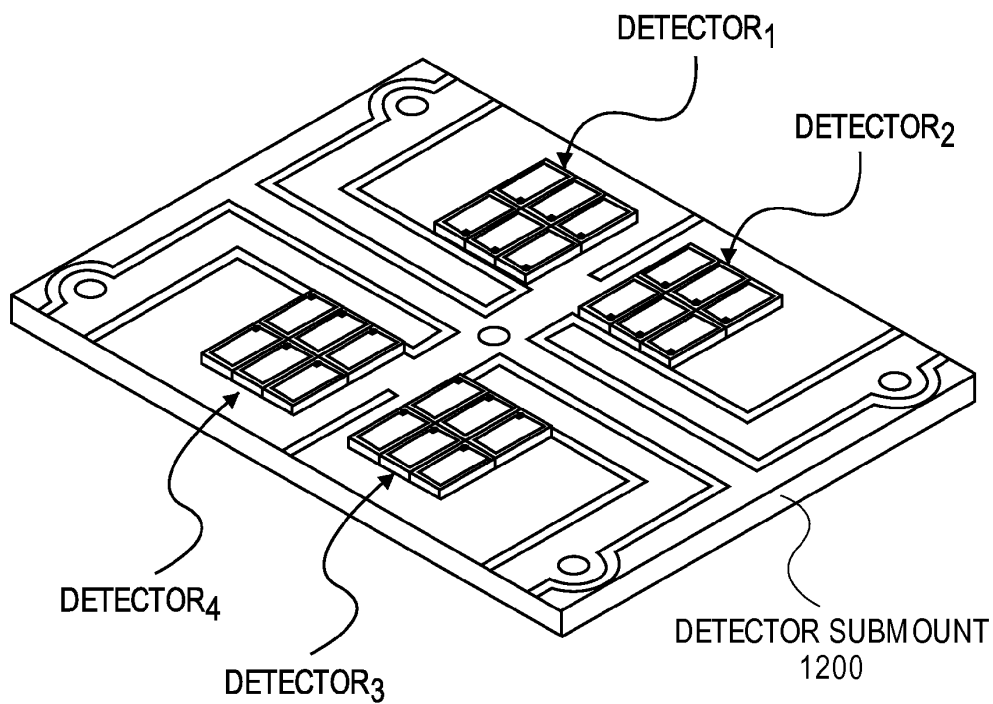


FIG. 11D



**FIG. 12A**

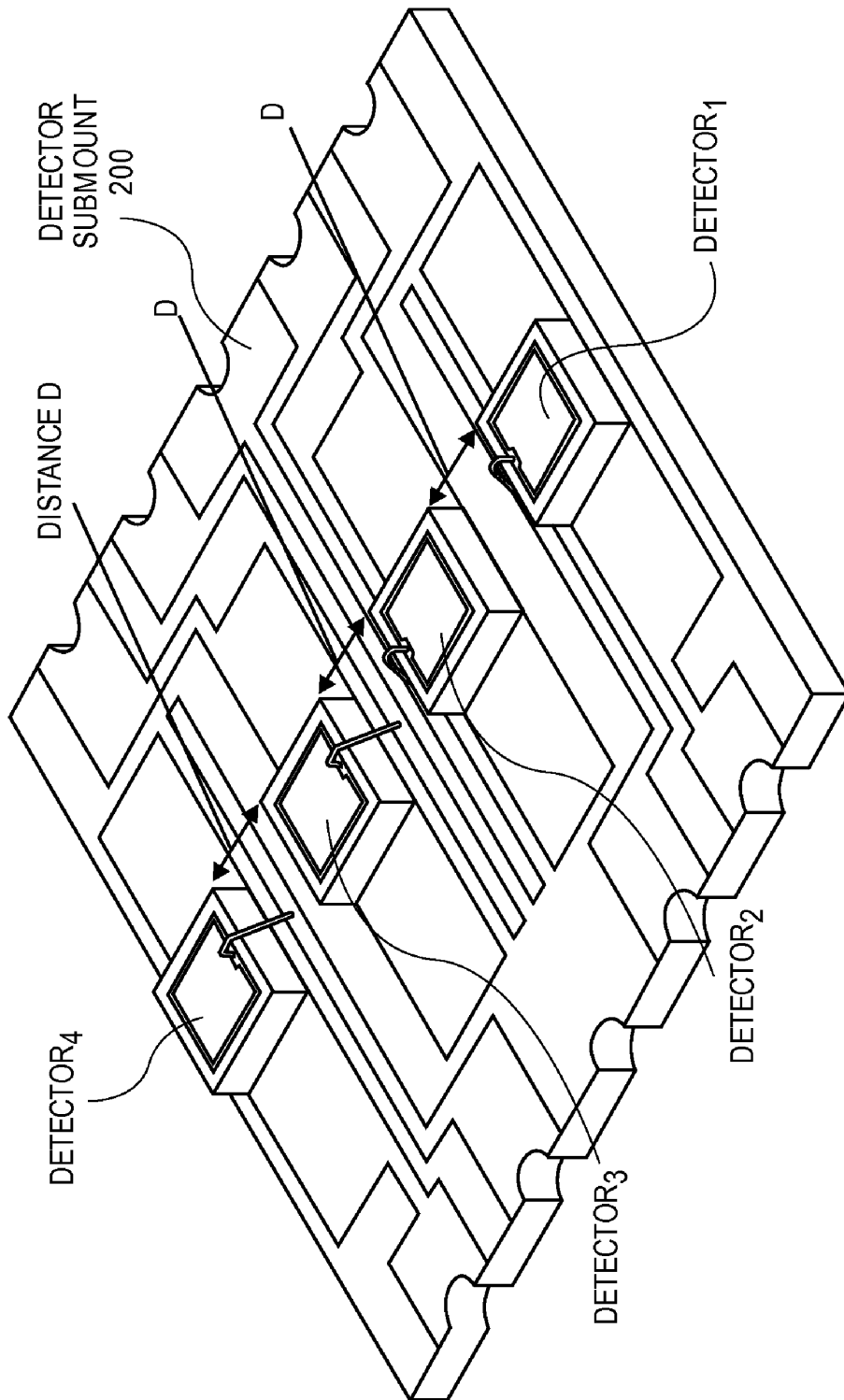
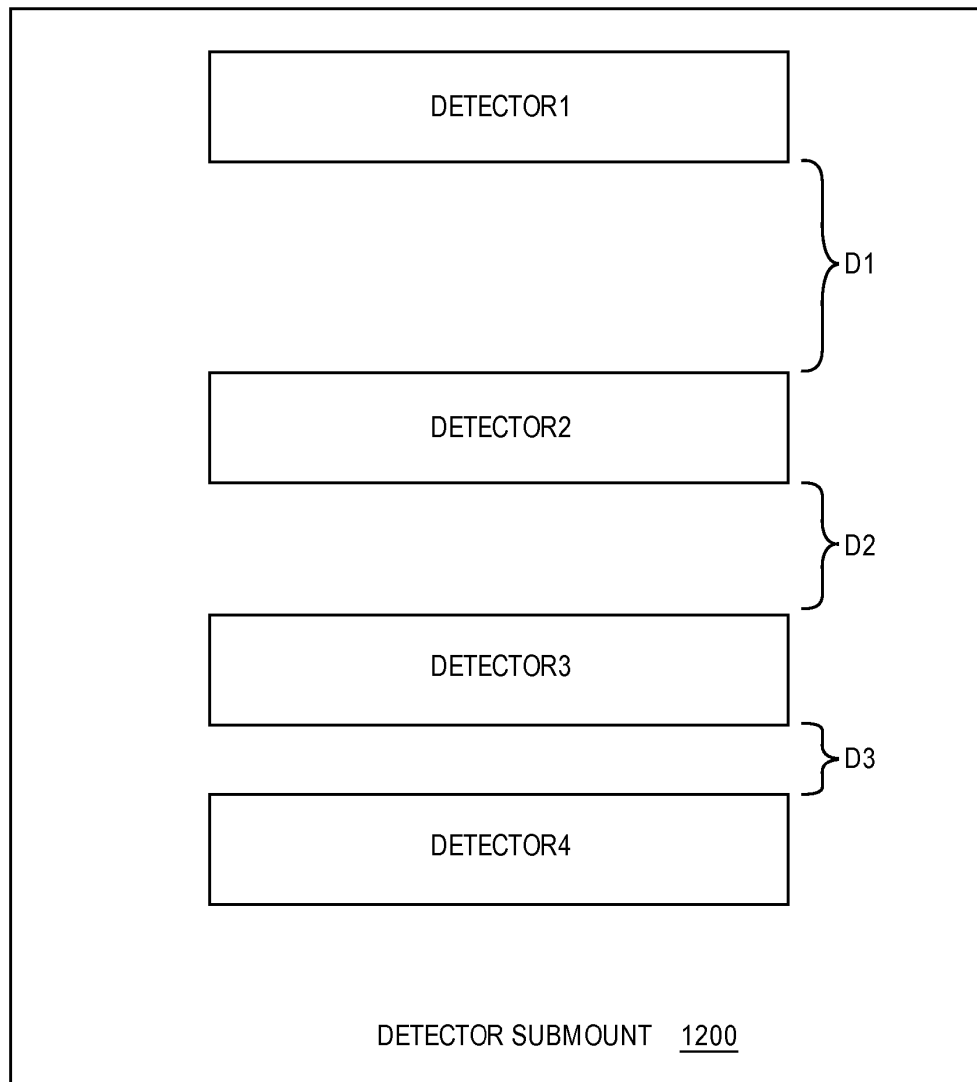
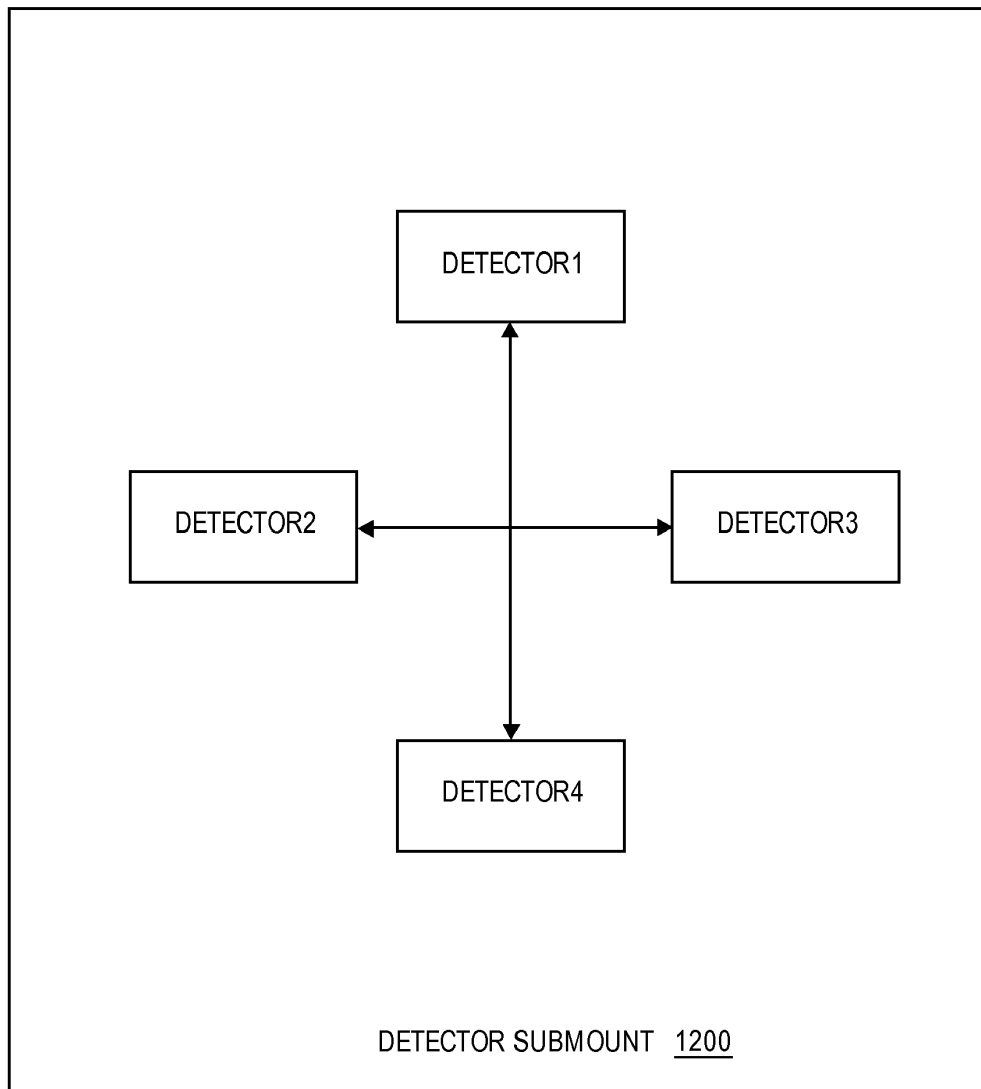


FIG. 12B

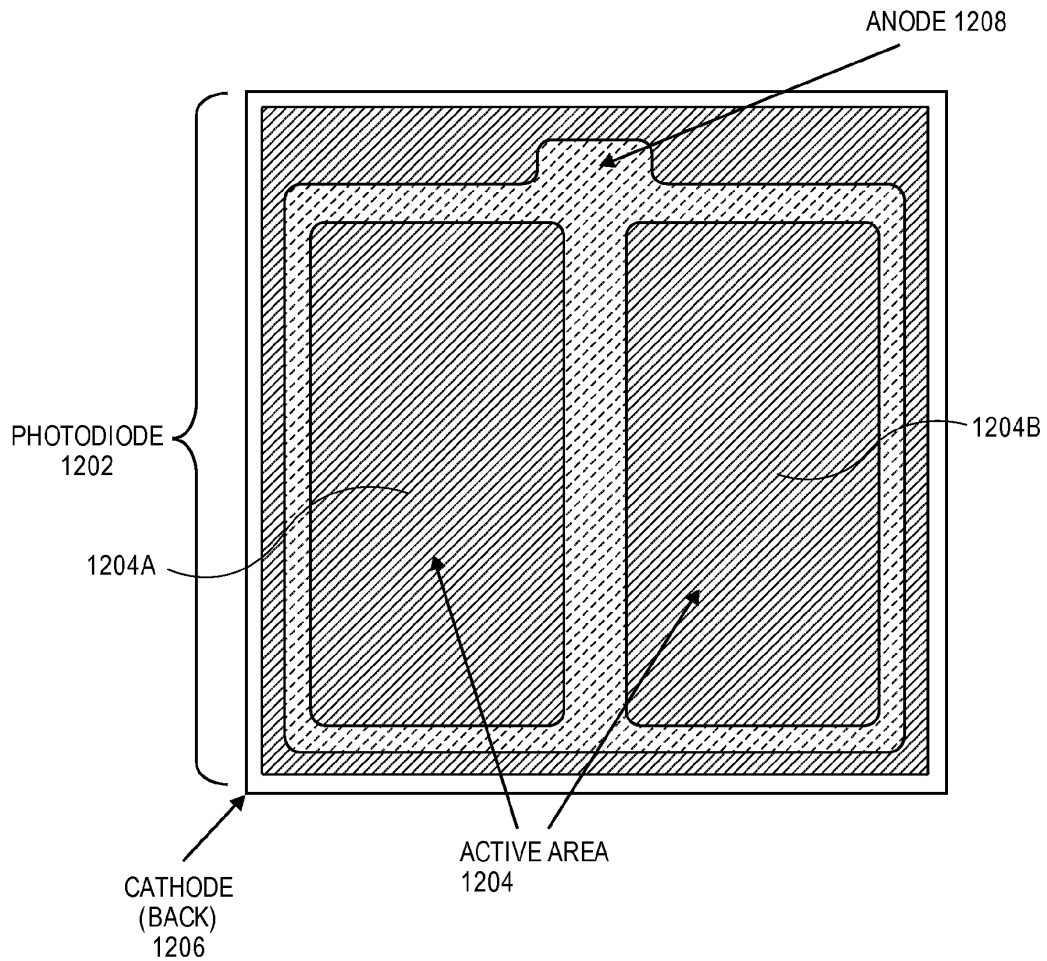




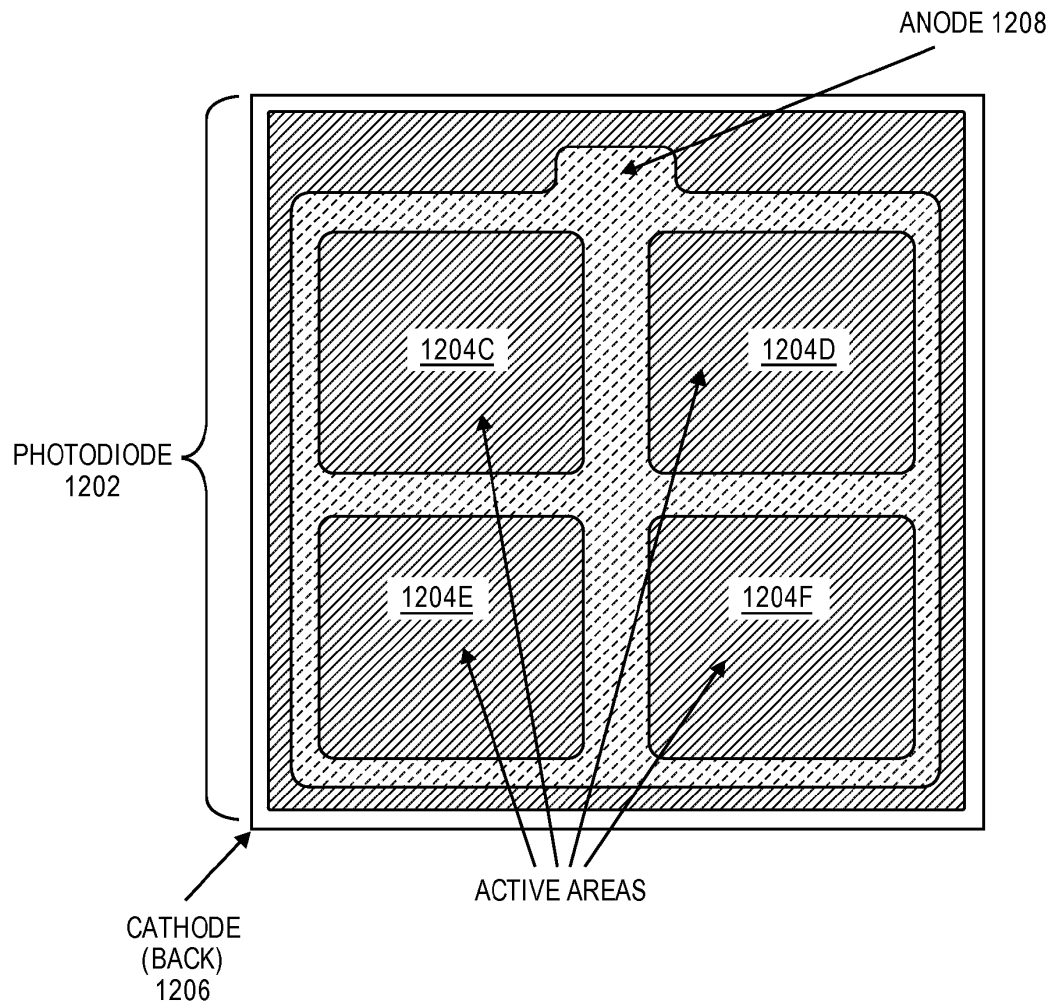
**FIG. 12C**



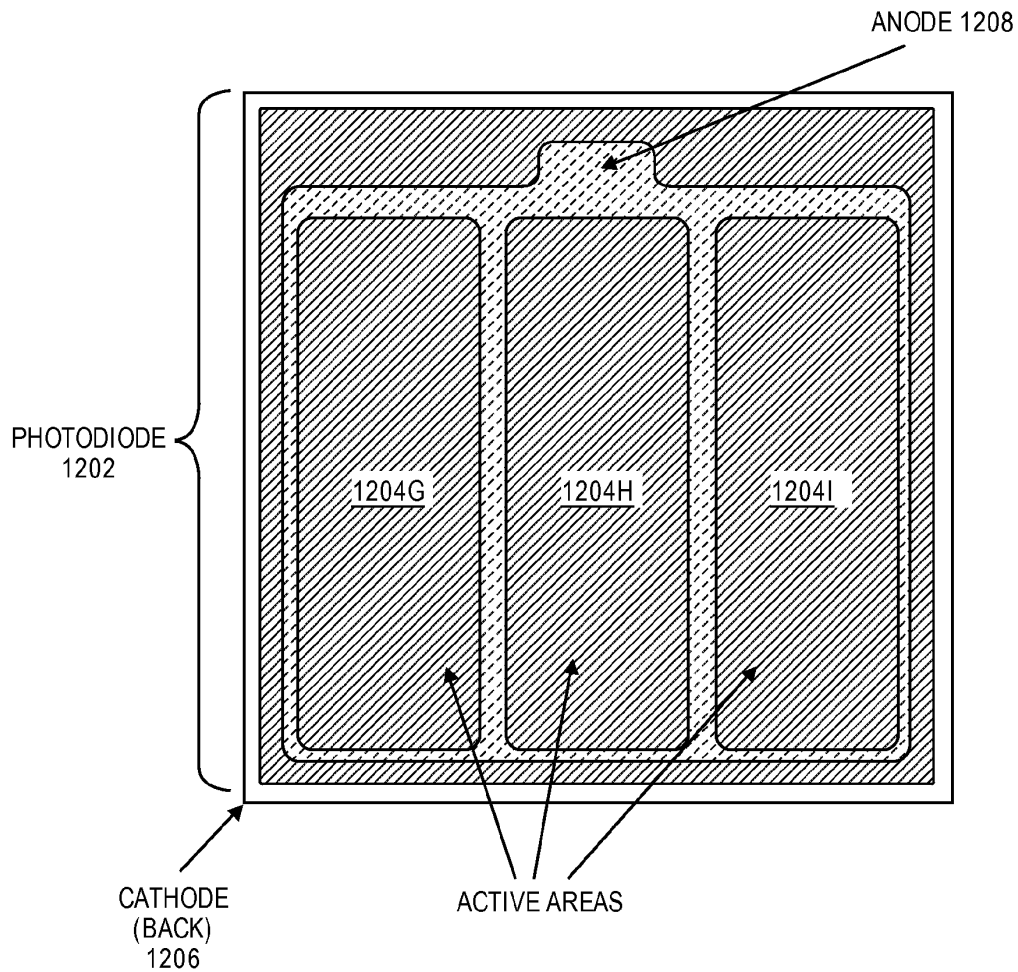
**FIG. 12D**



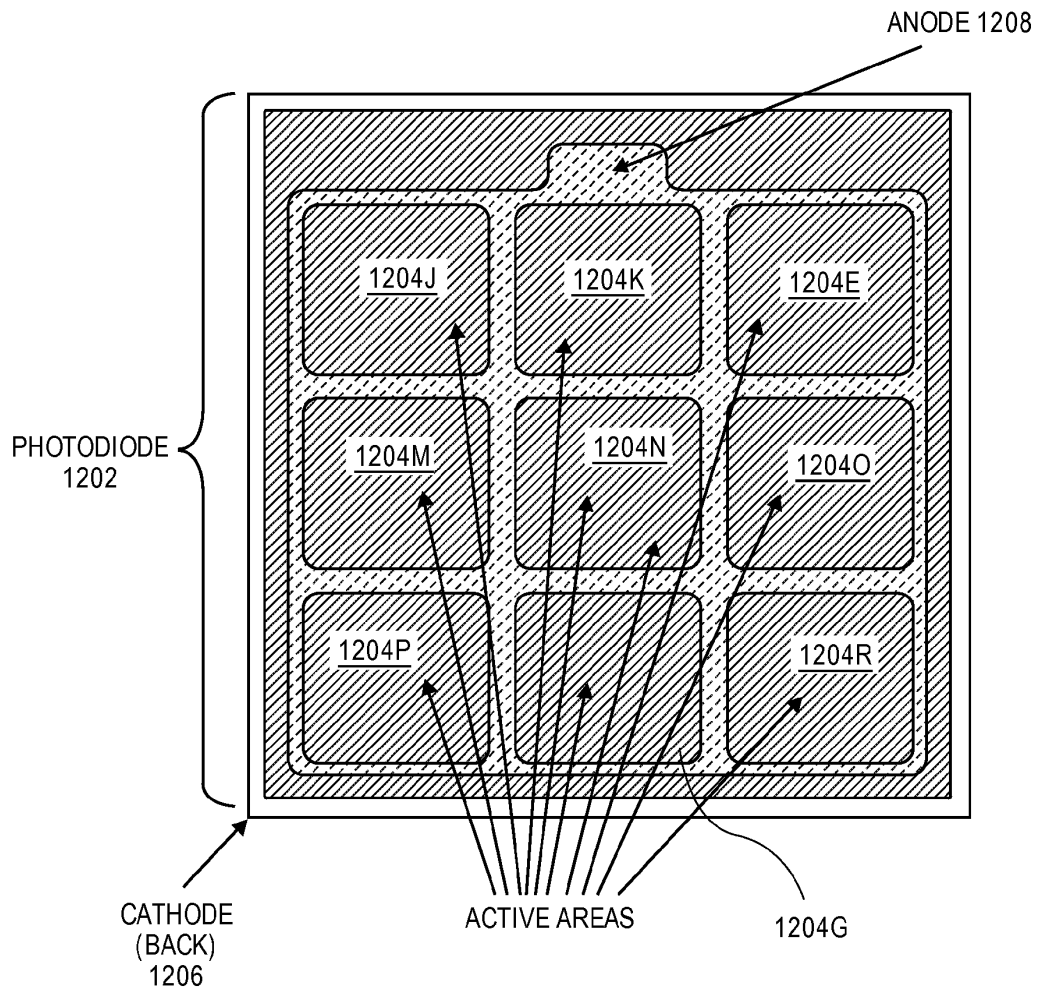
**FIG. 12E**



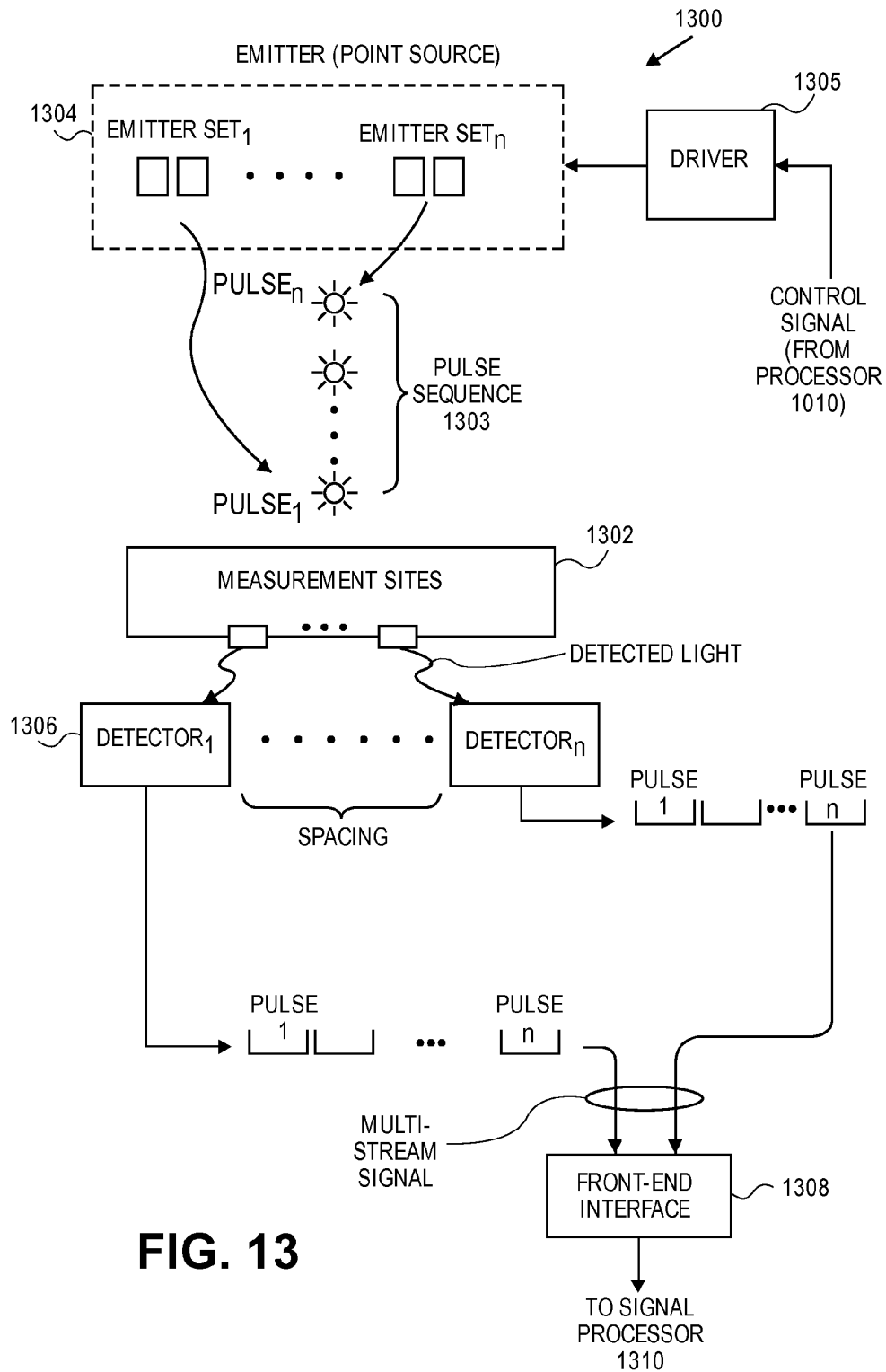
**FIG. 12F**

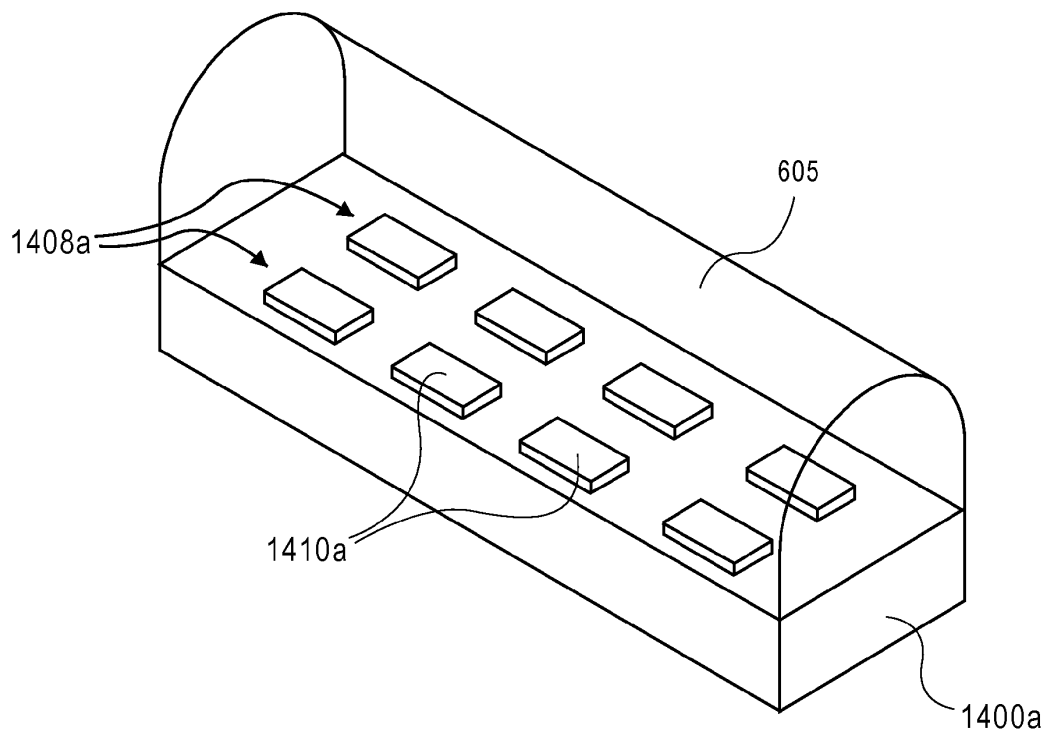


**FIG. 12G**



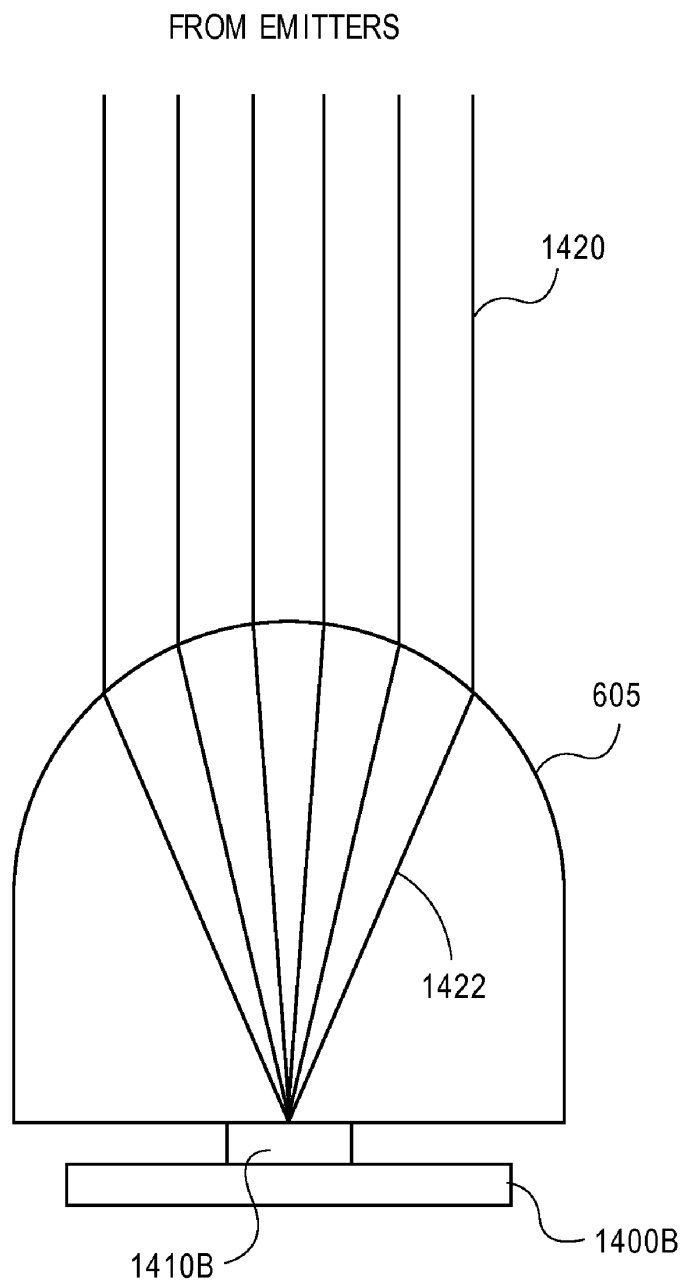
**FIG. 12H**

**FIG. 13**

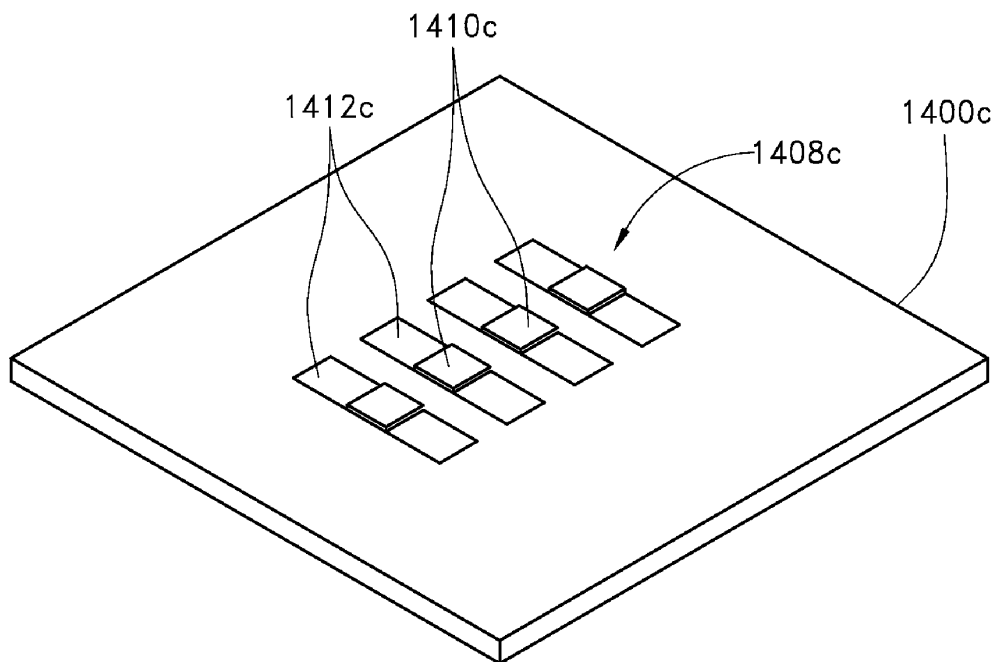


**FIG. 14A**

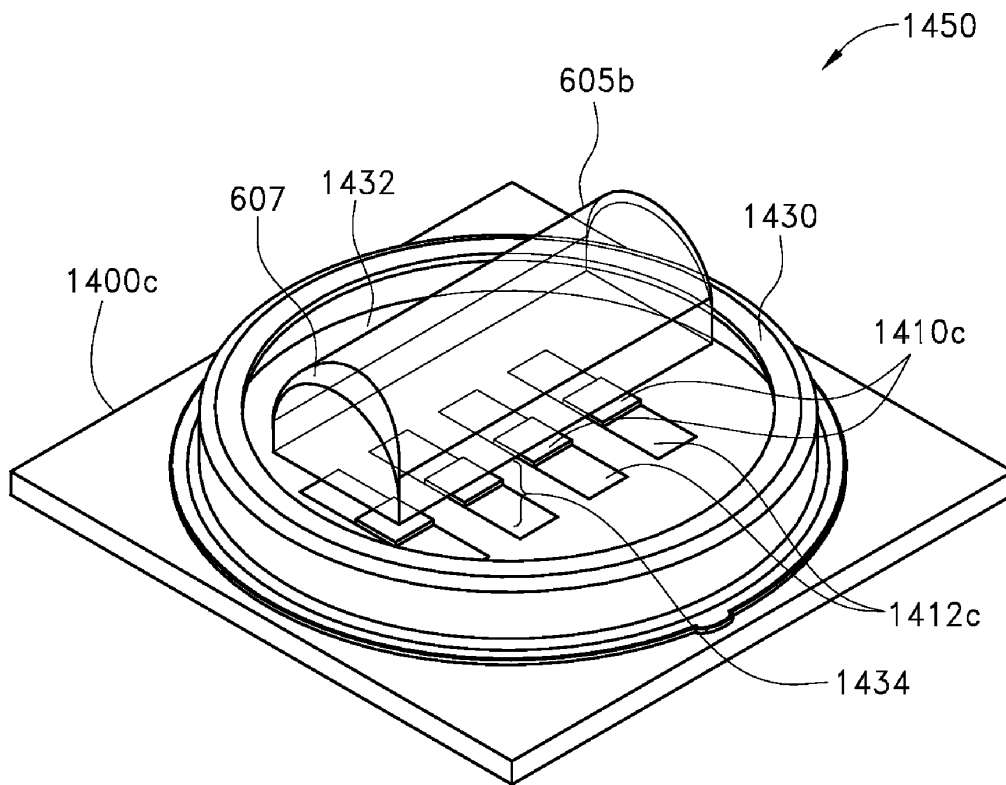




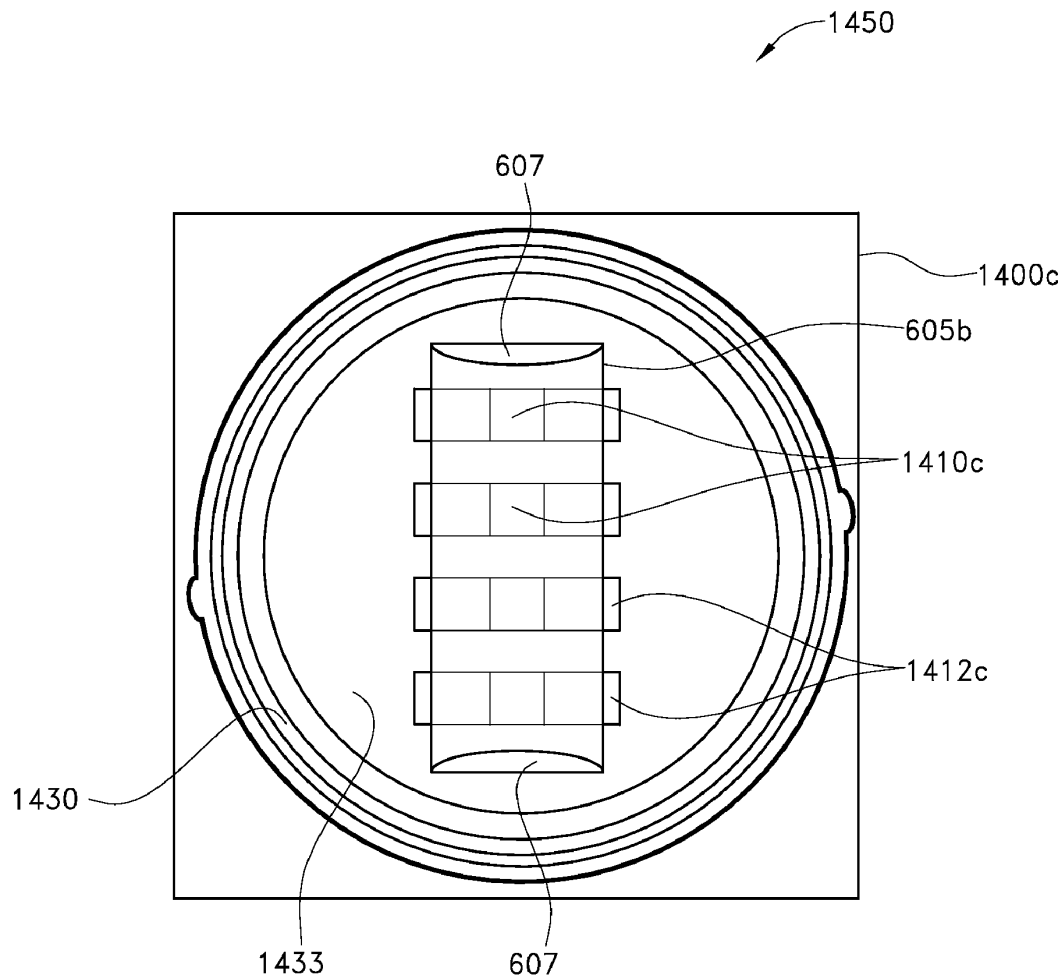
**FIG. 14B**



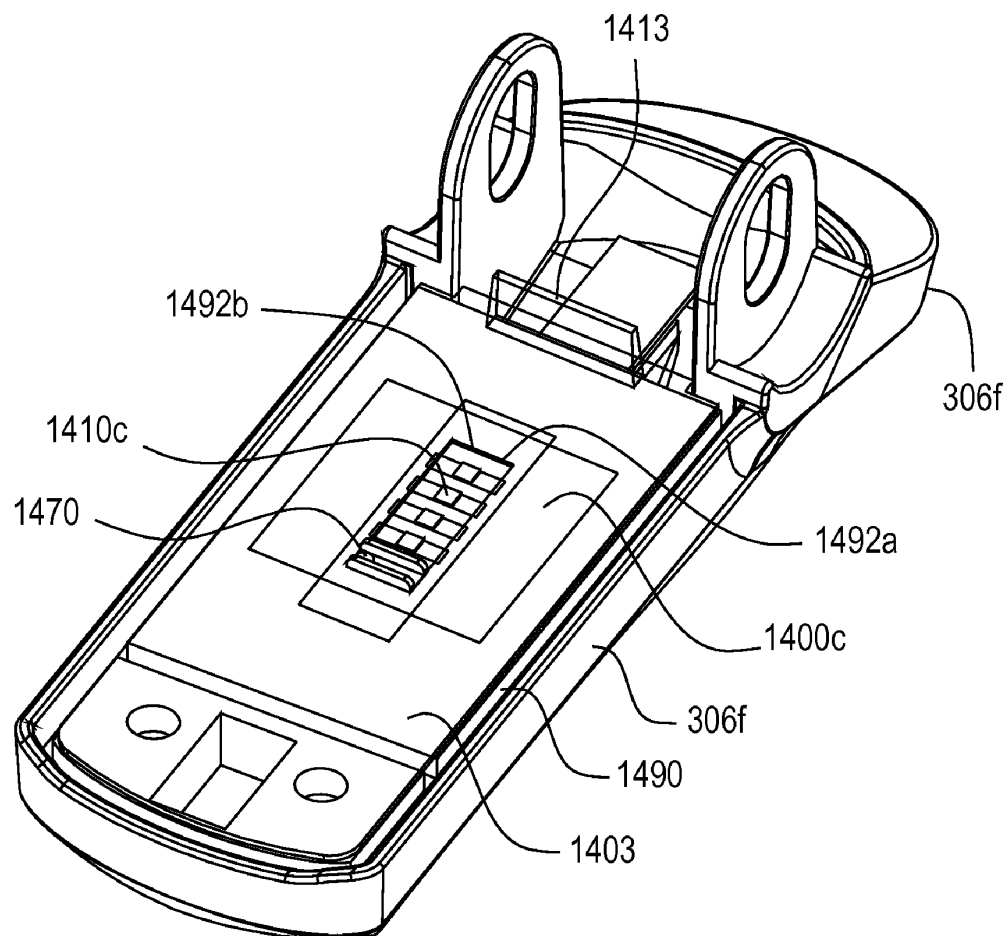
**FIG. 14C**



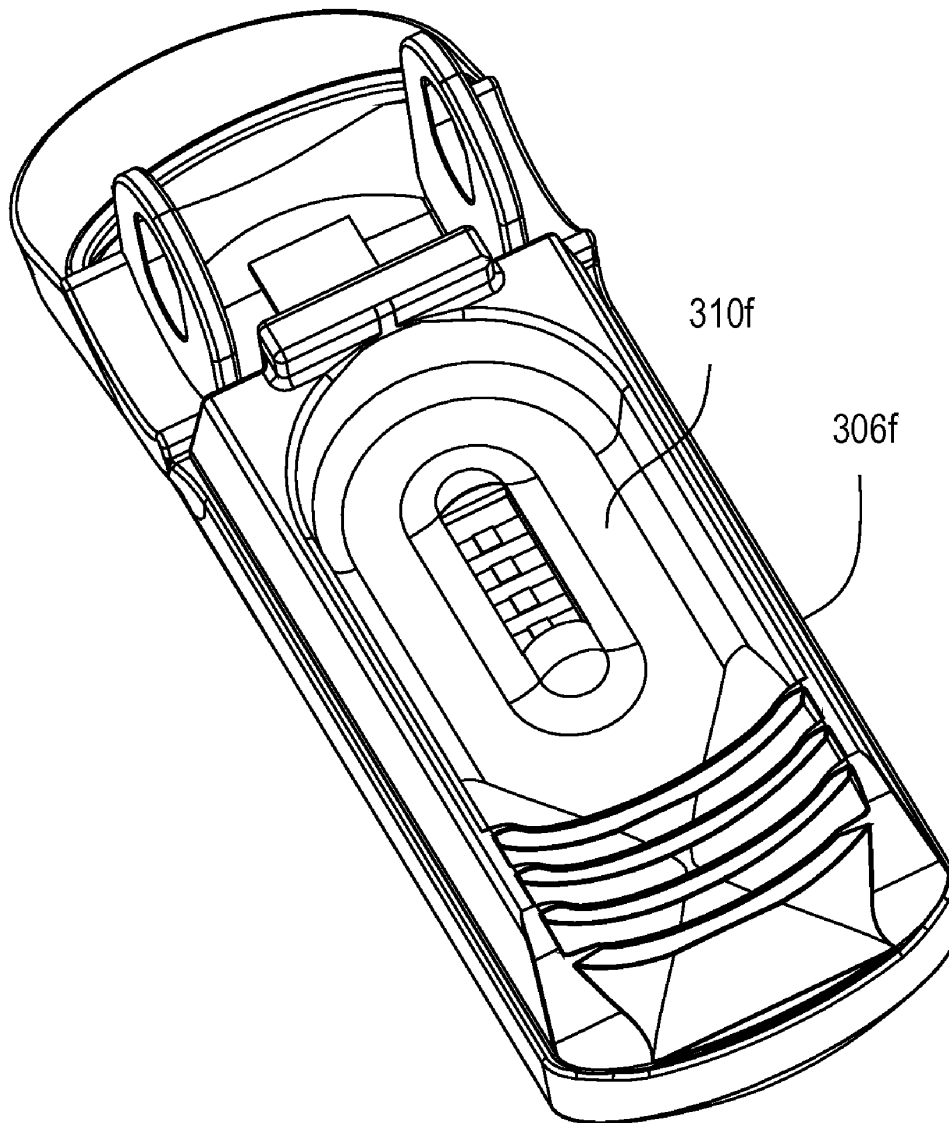
**FIG. 14D**



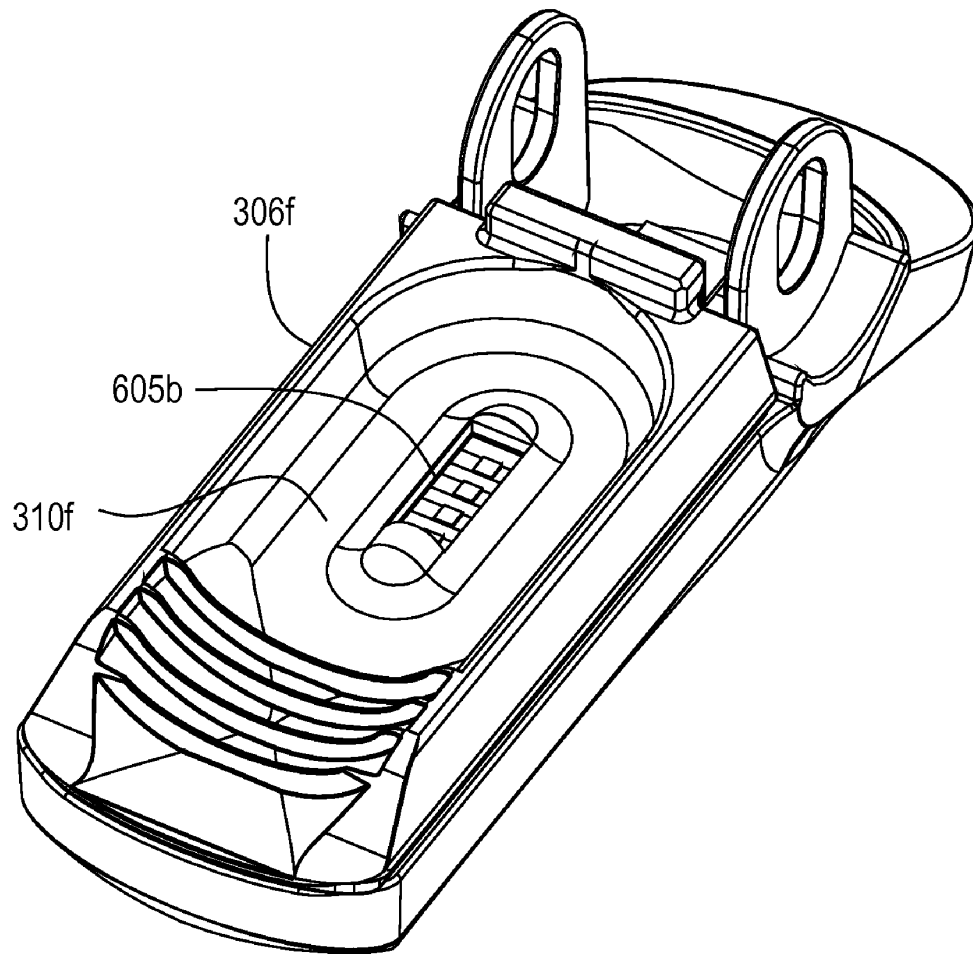
**FIG. 14E**



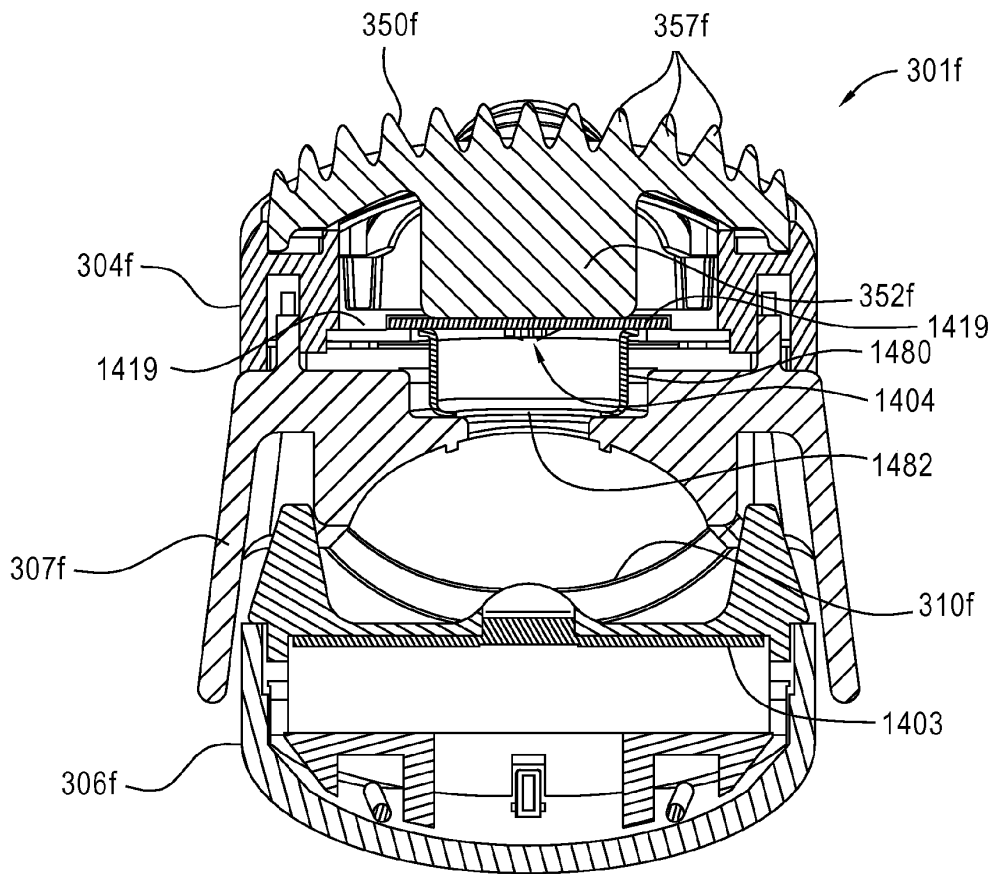
**FIG. 14F**



**FIG. 14G**



**FIG. 14H**



**FIG. 14I**



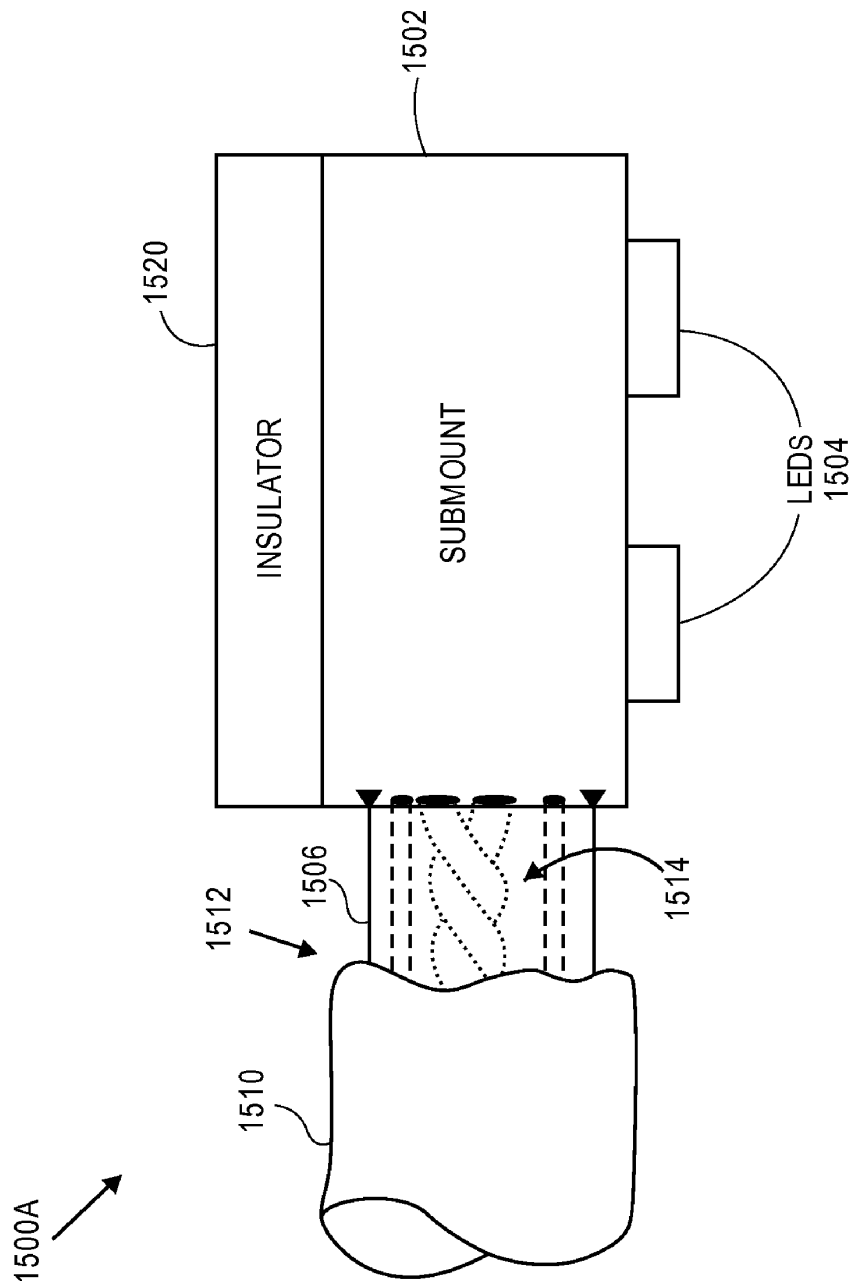


FIG. 15A

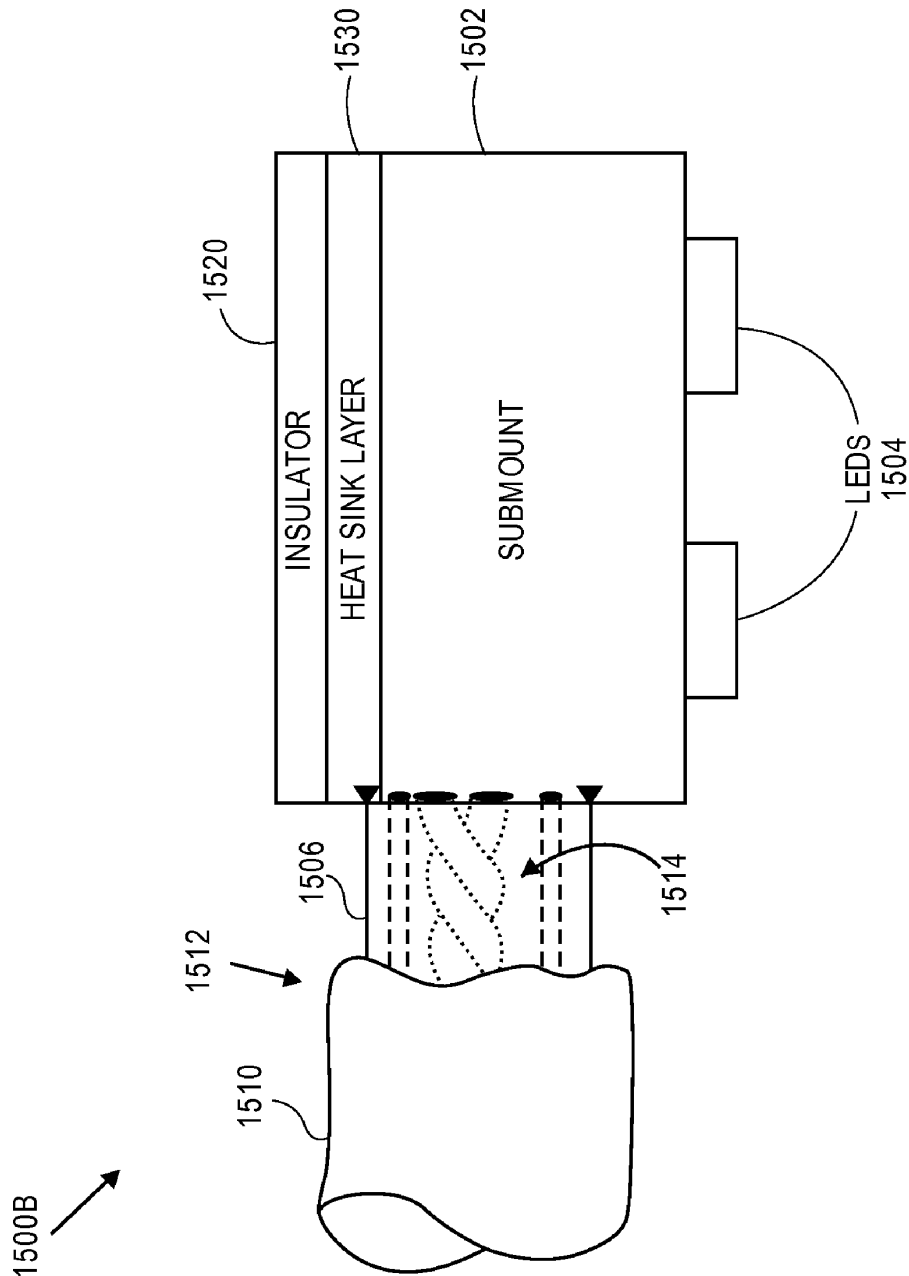
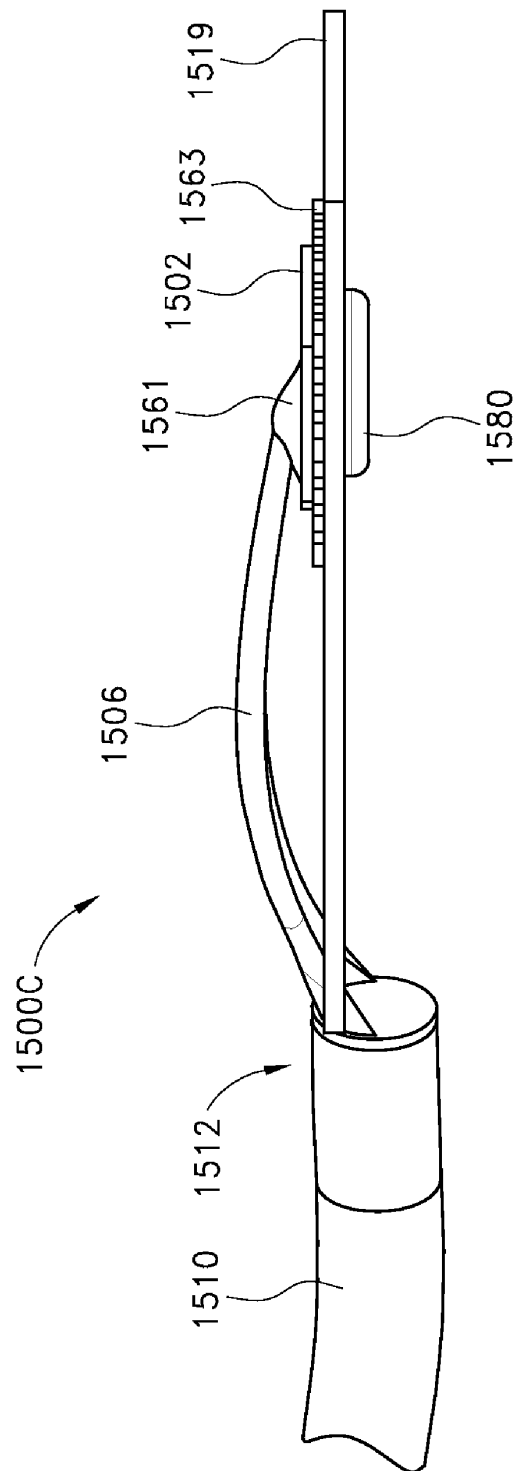


FIG. 15B



**FIG. 15C**

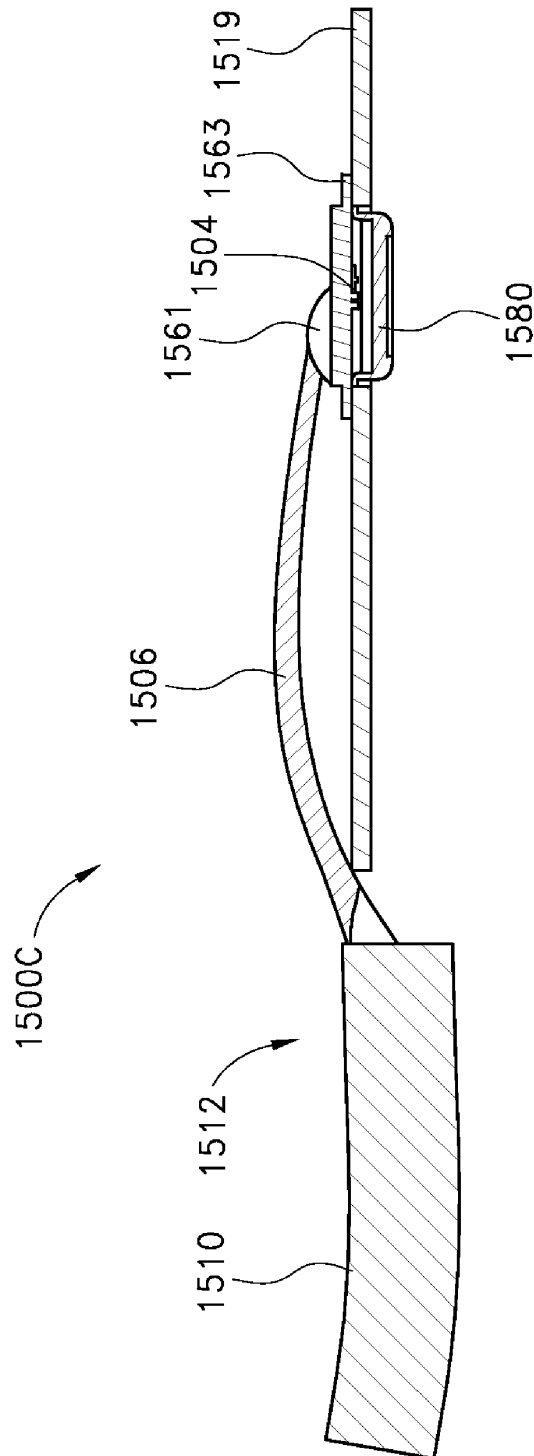


FIG. 15D

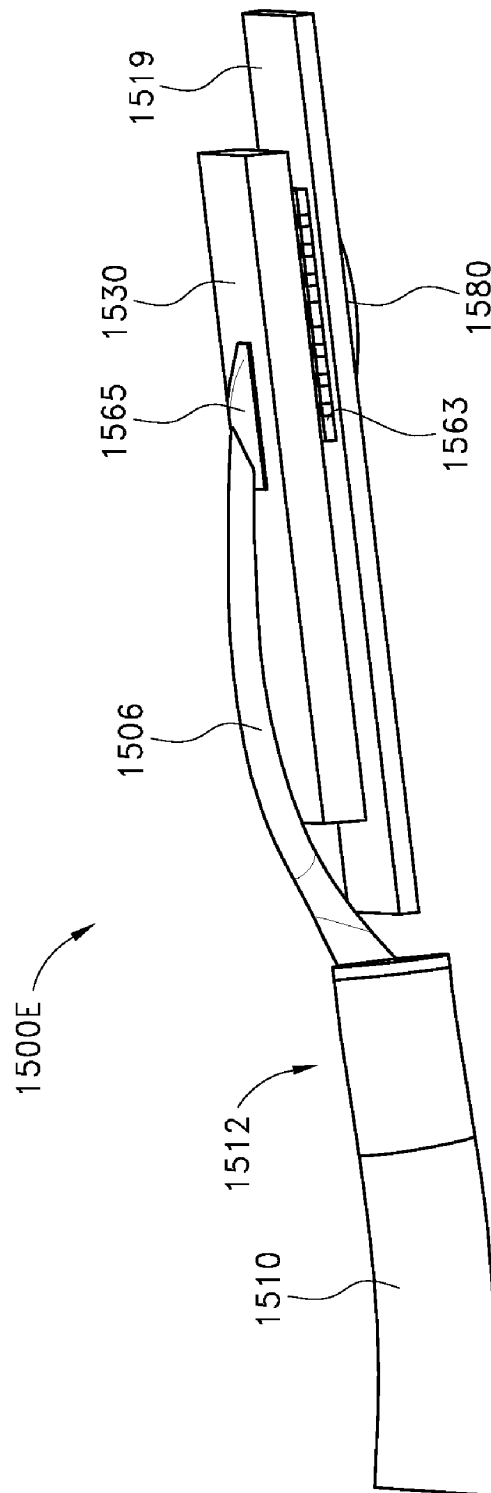
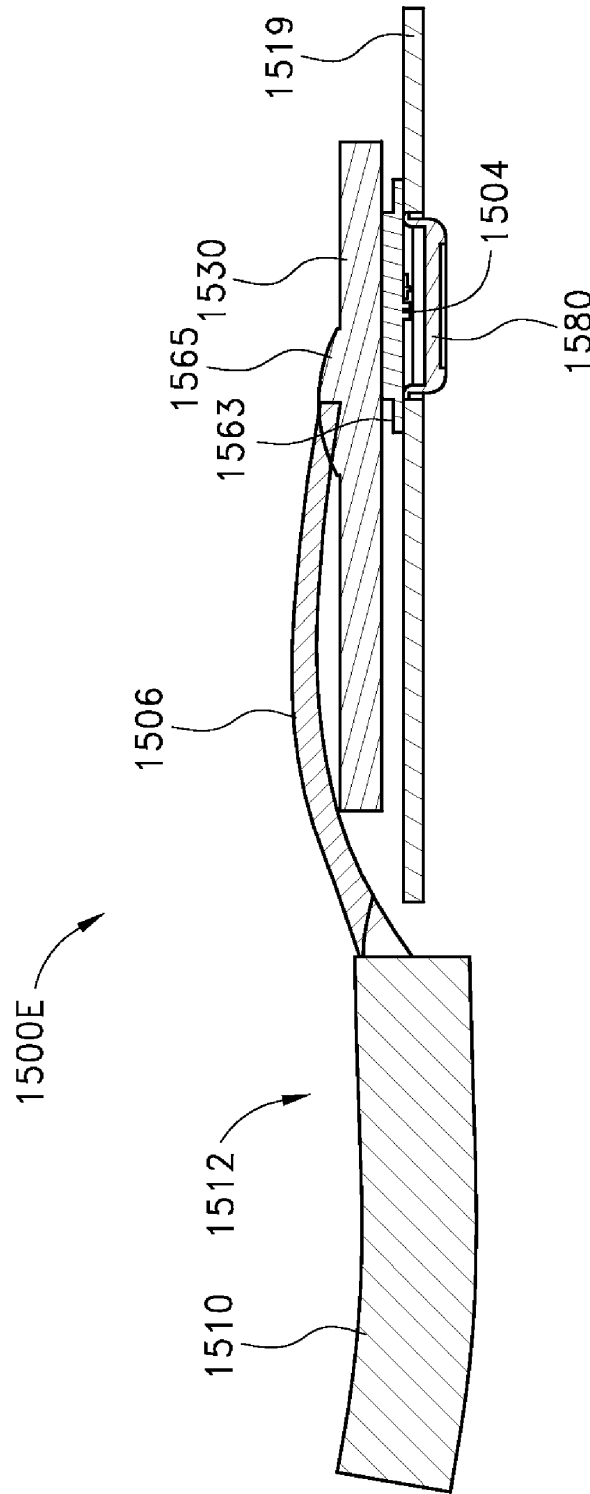
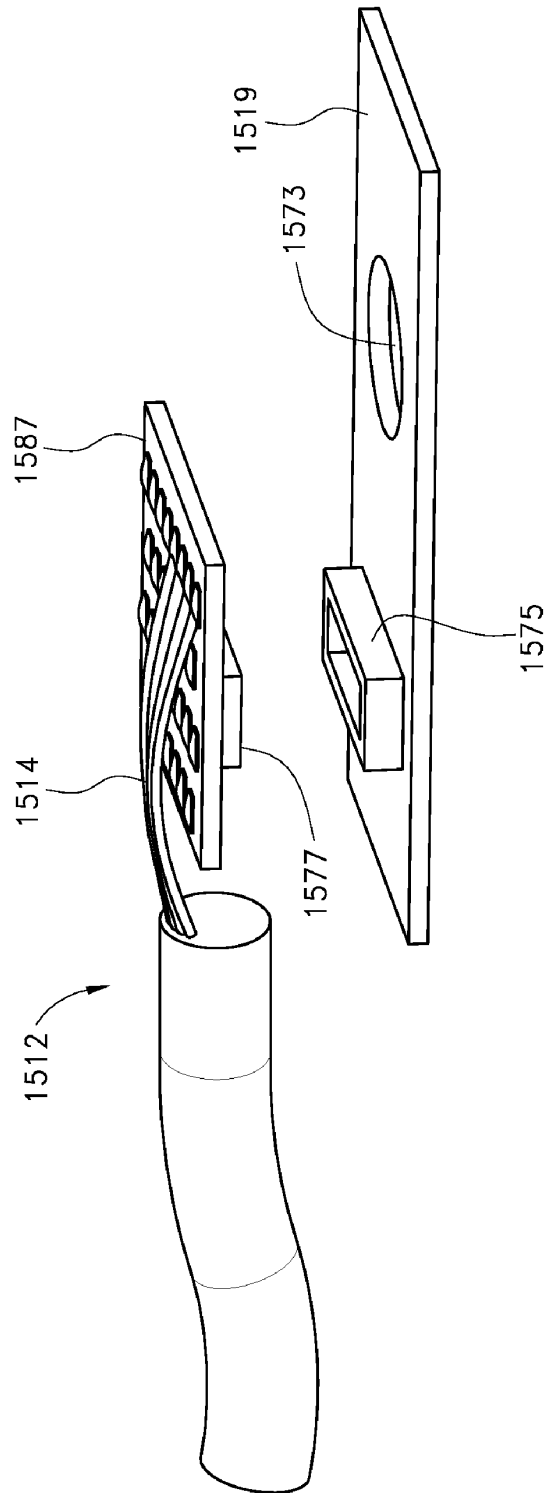


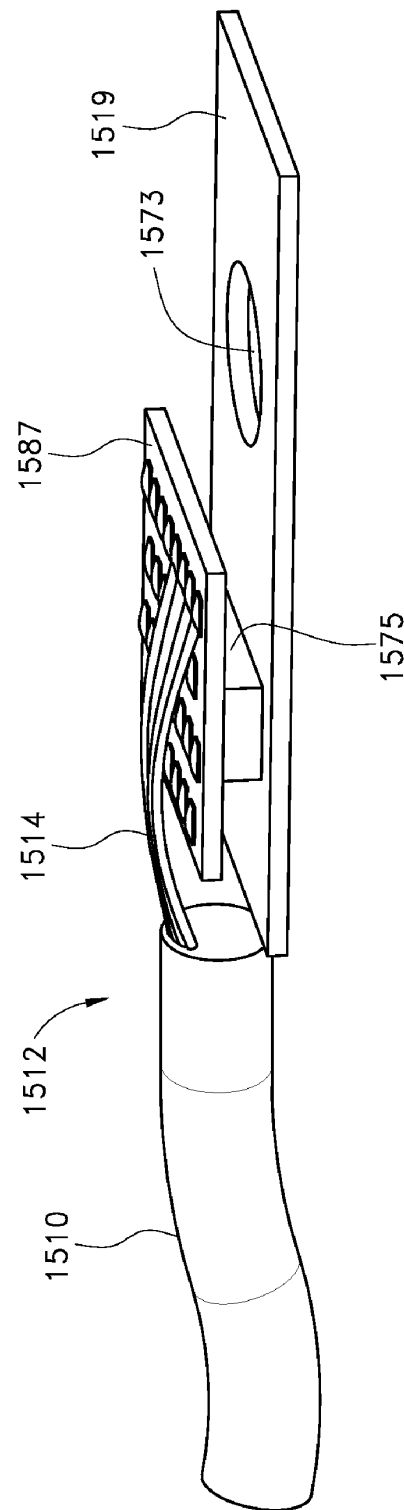
FIG. 15E



**FIG. 15F**



**FIG. 15G**



**FIG. 15H**



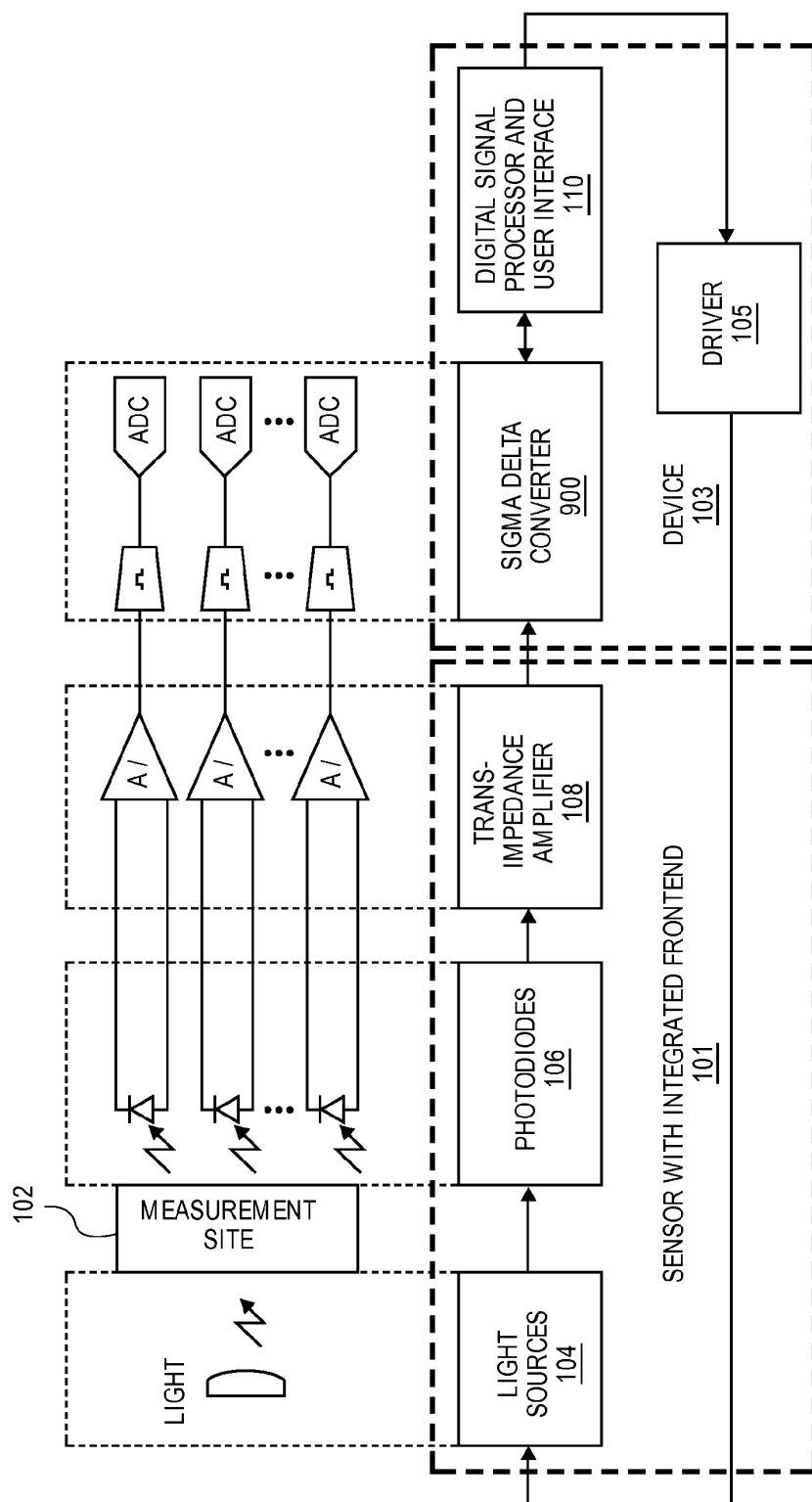
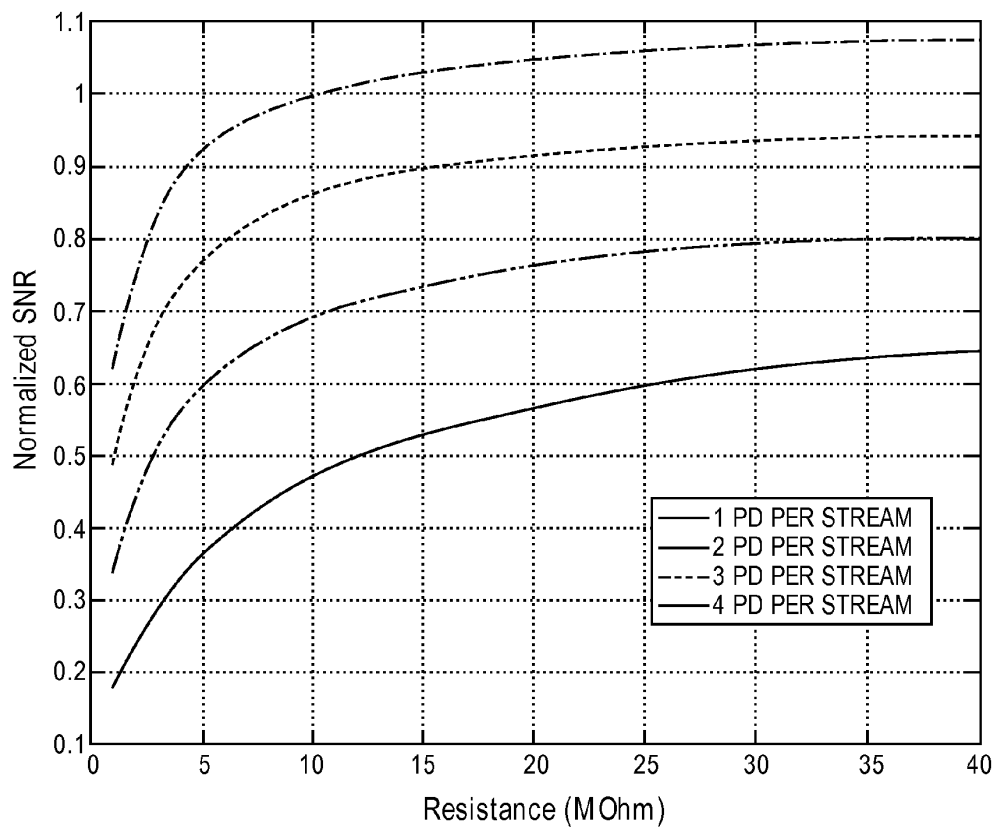
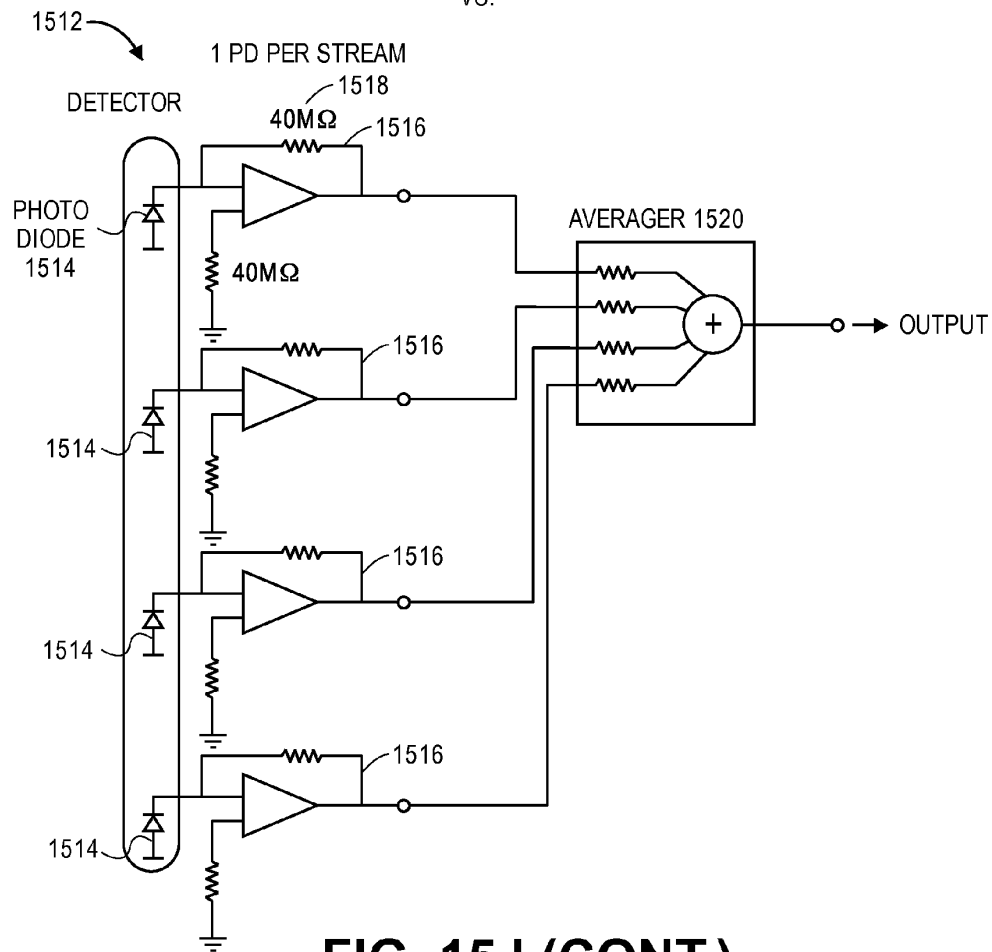
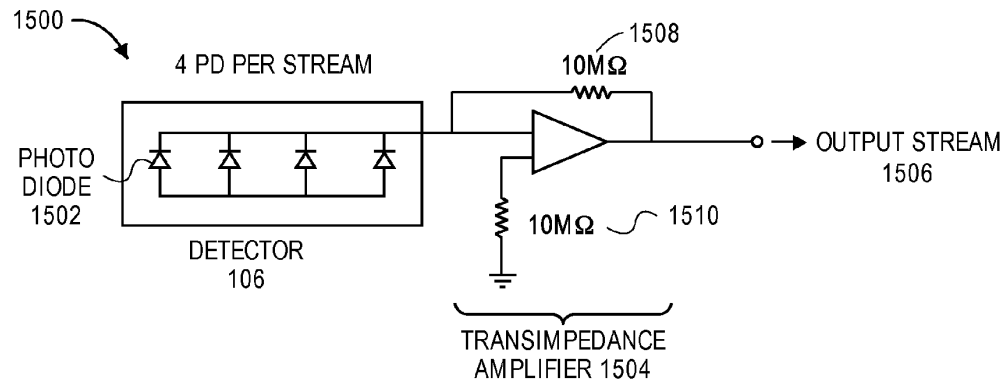
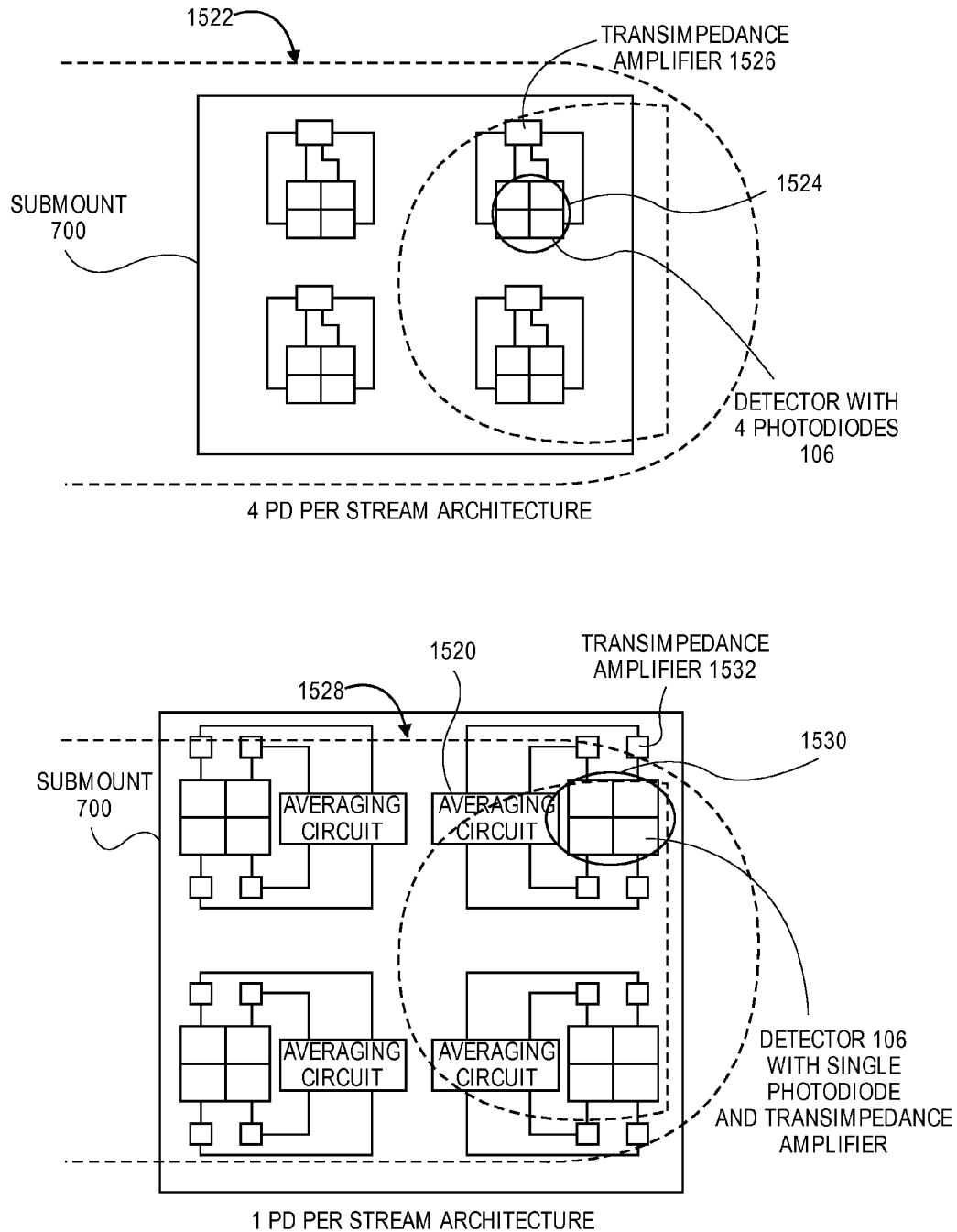


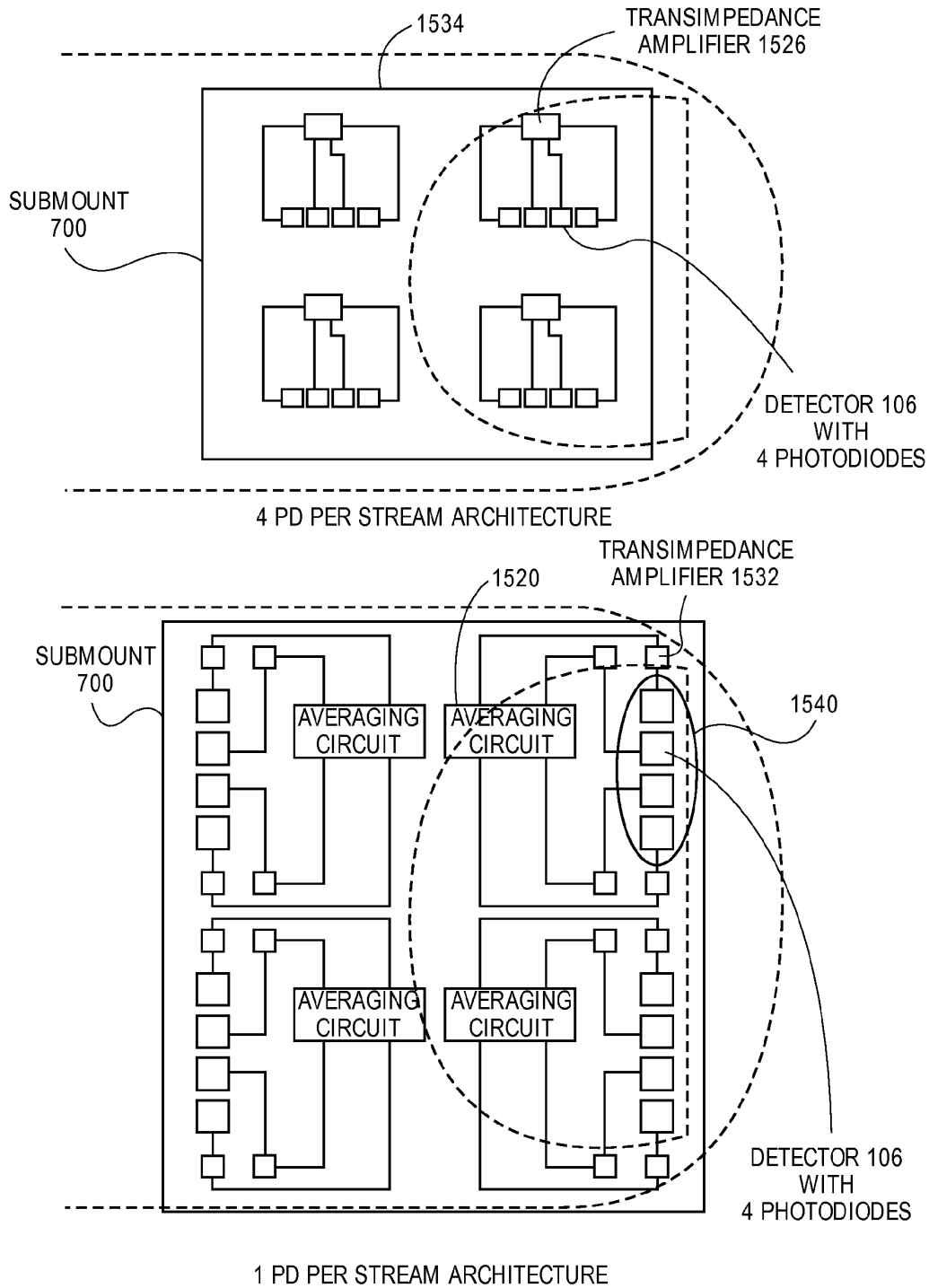
FIG. 15I

**FIG. 15J**

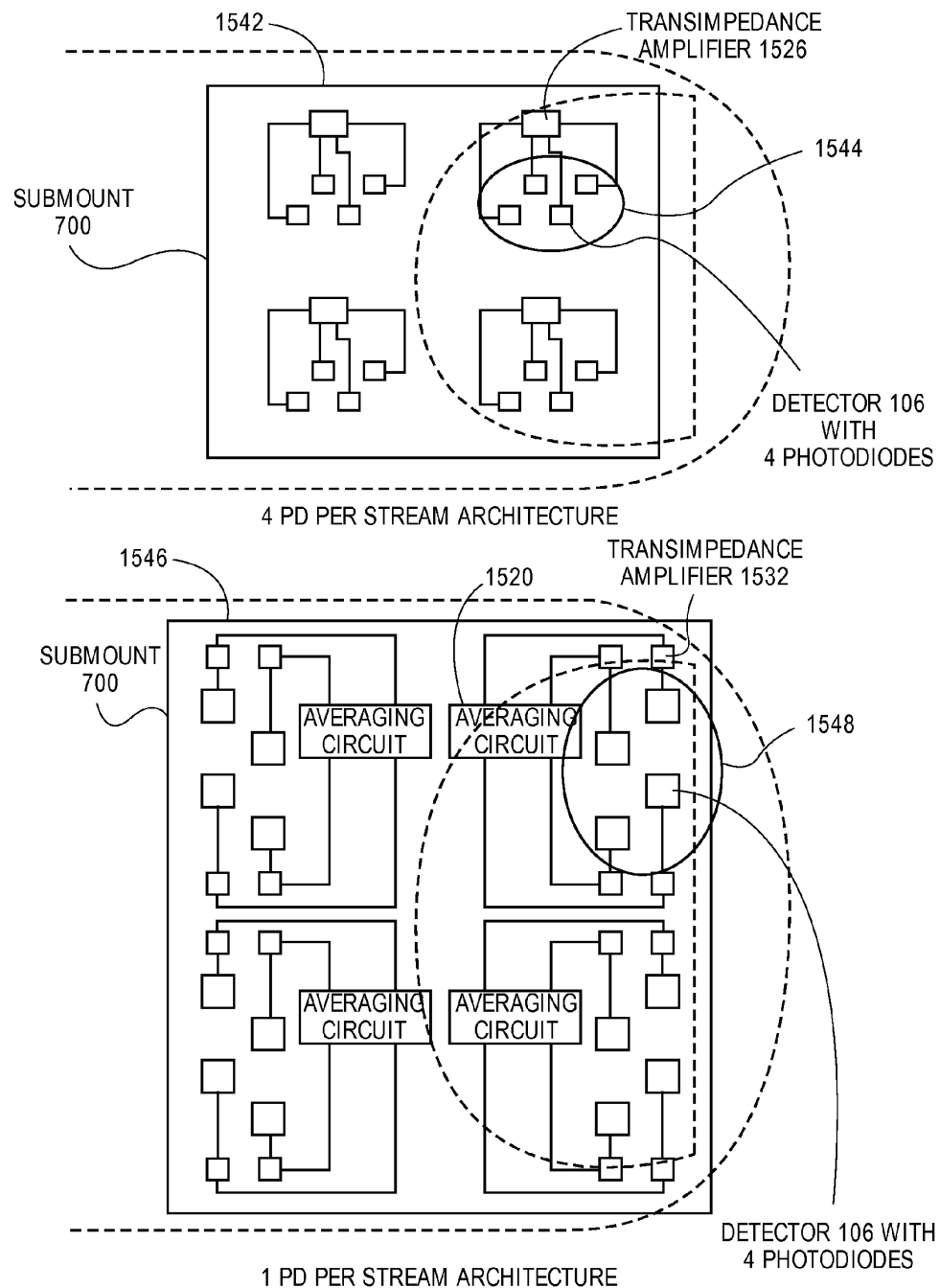


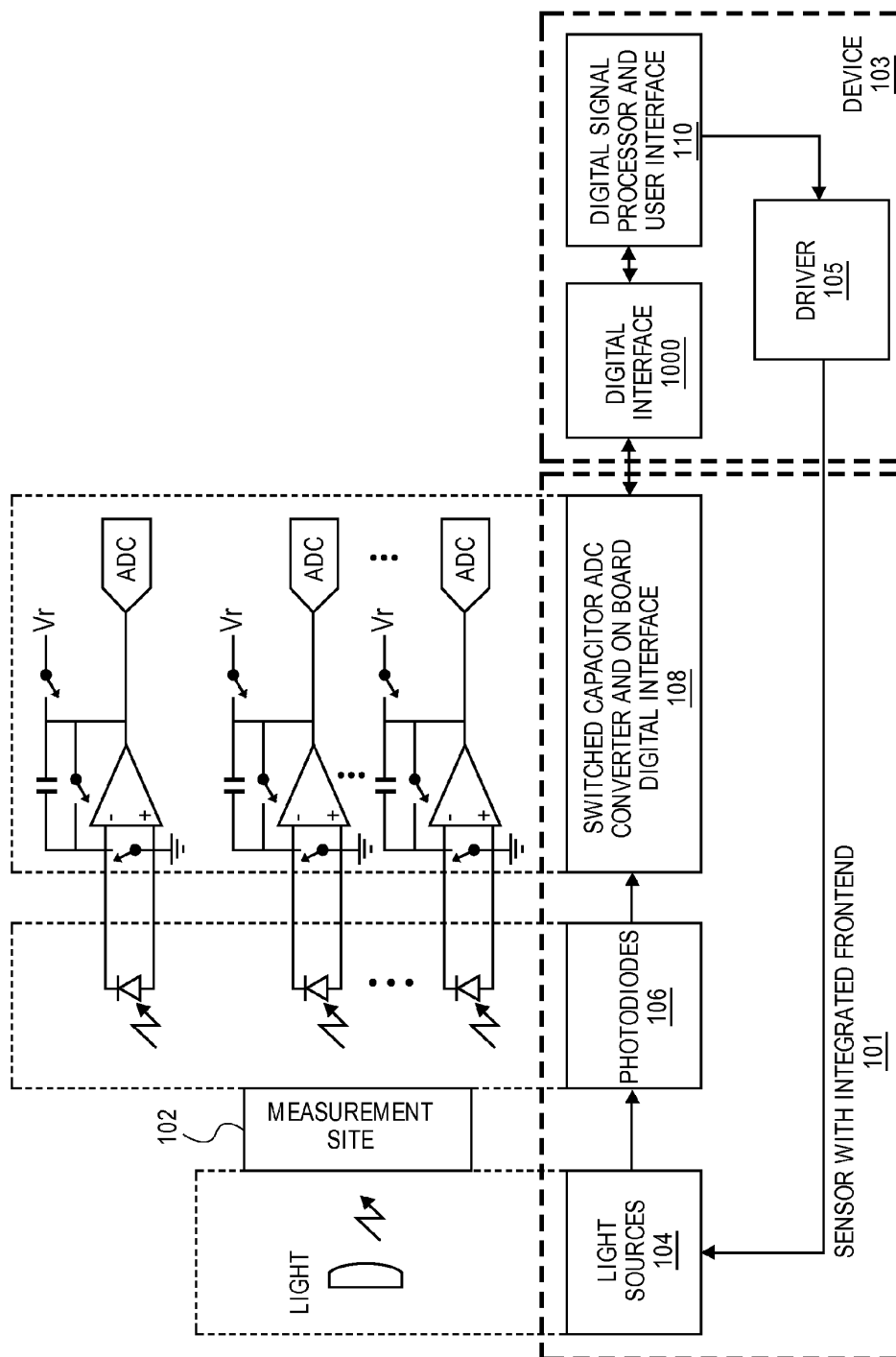


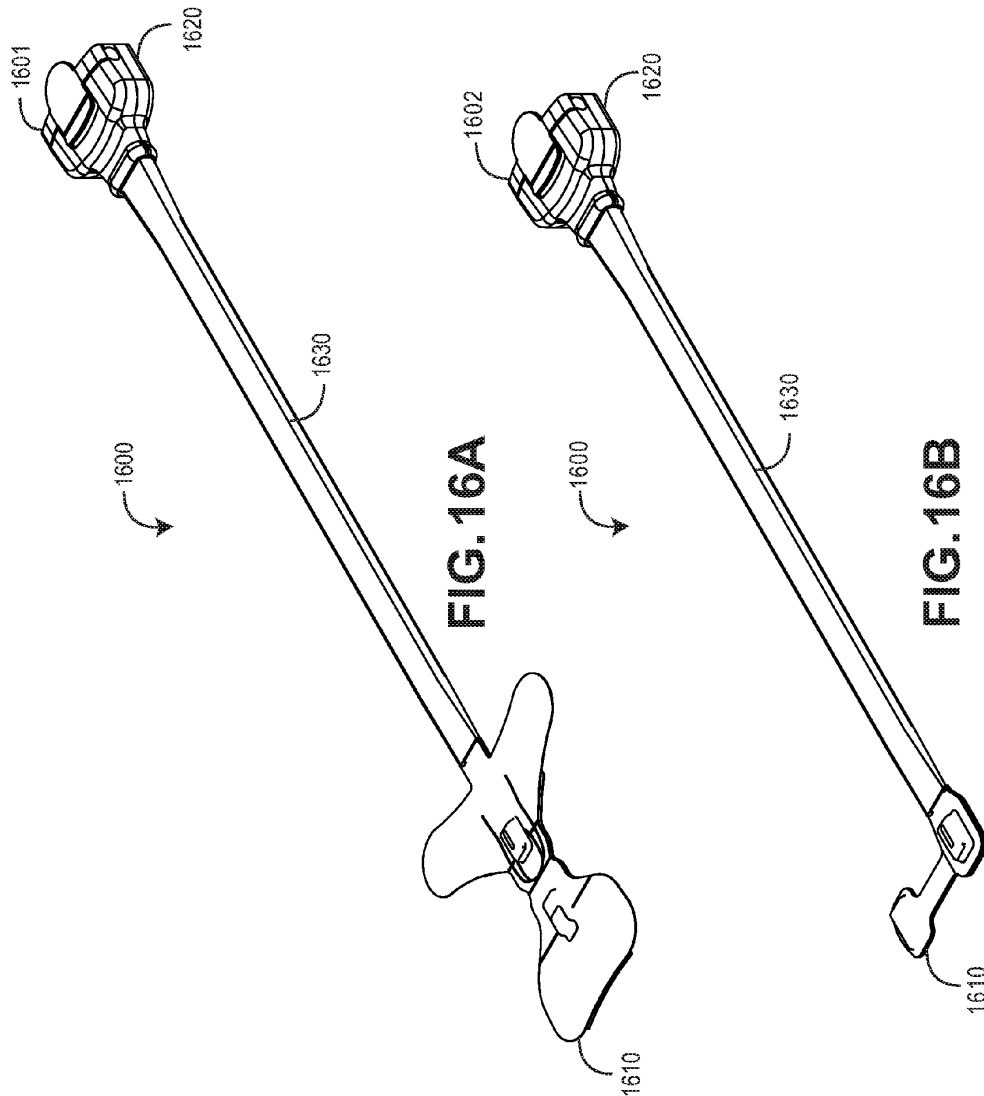
**FIG. 15K**



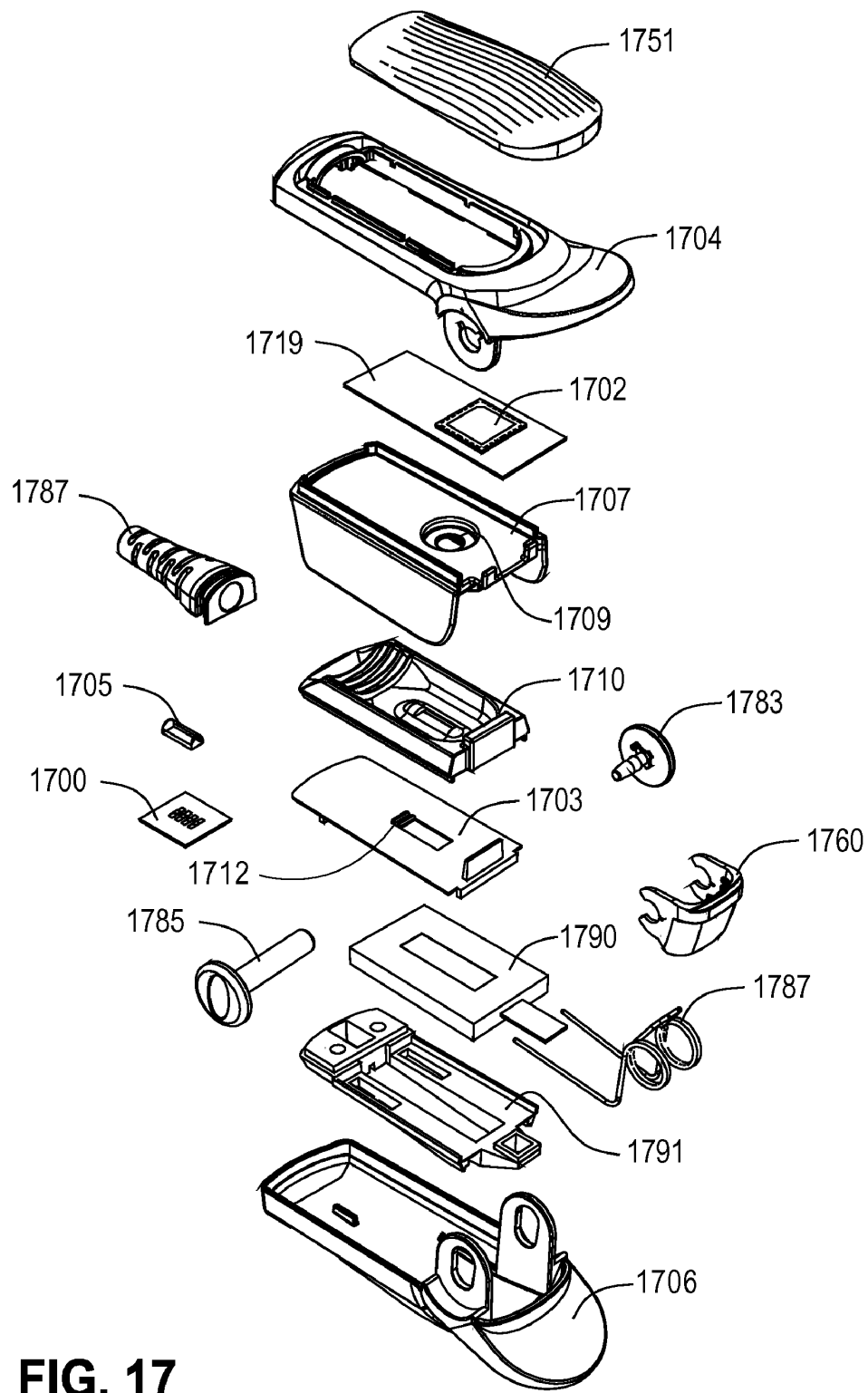
**FIG. 15K (CONT.)**

**FIG. 15K (CONT.)**

**FIG. 15L**

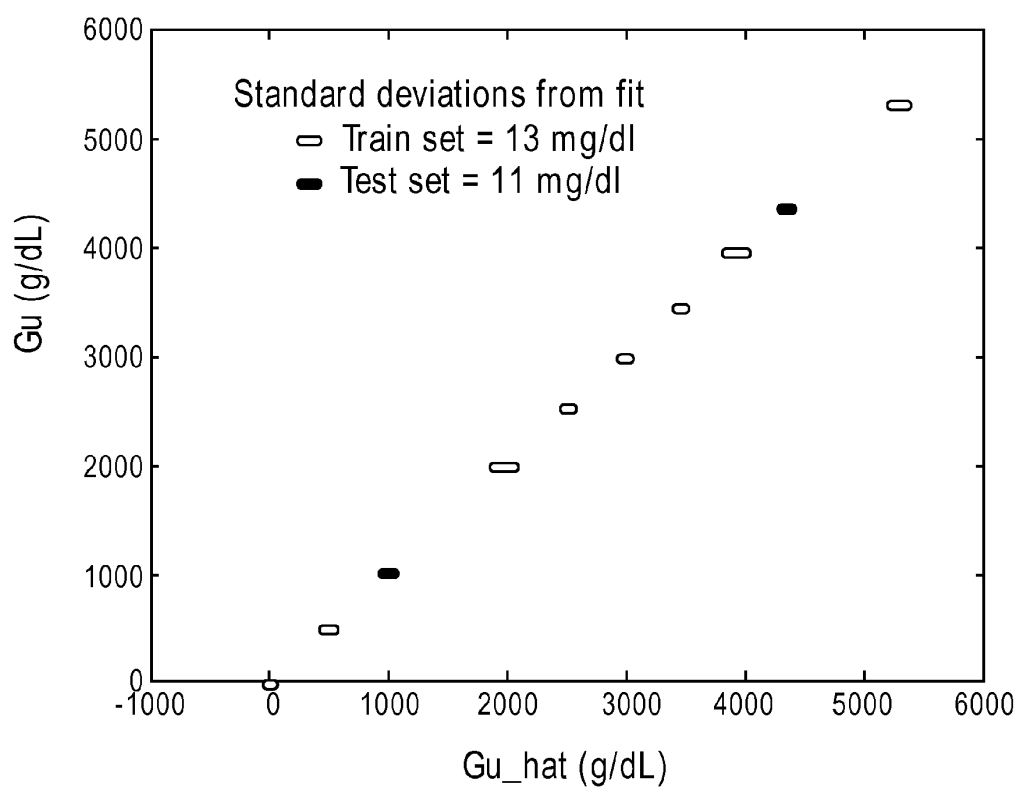


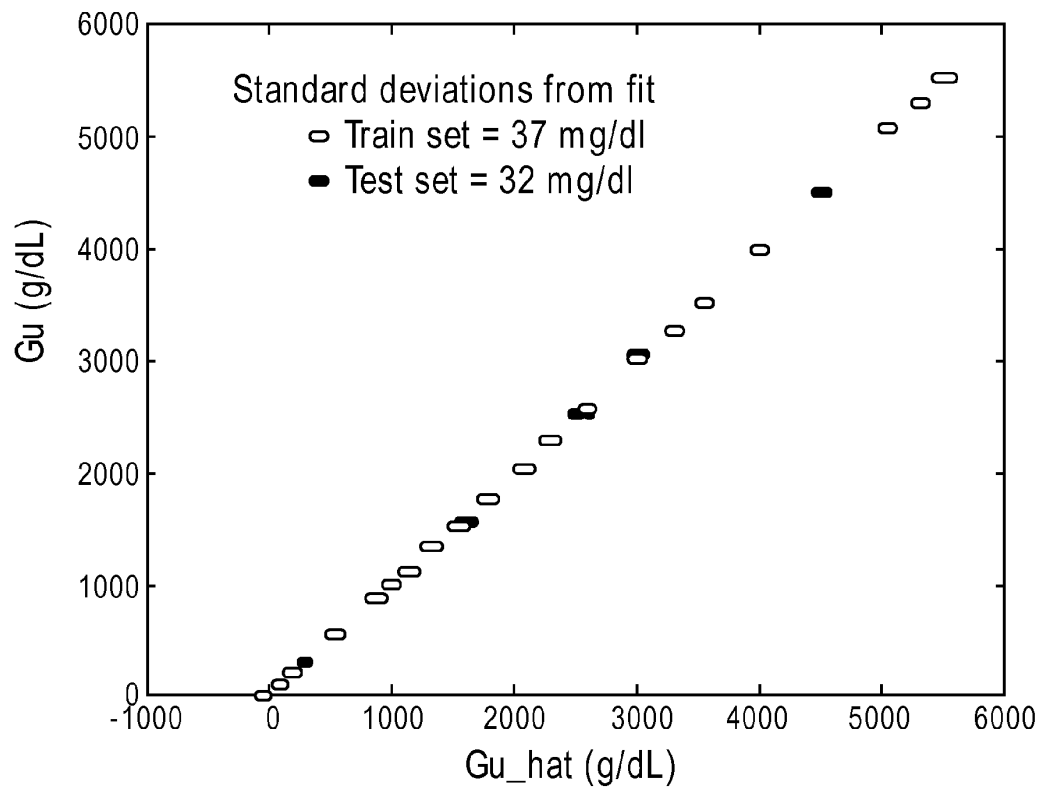




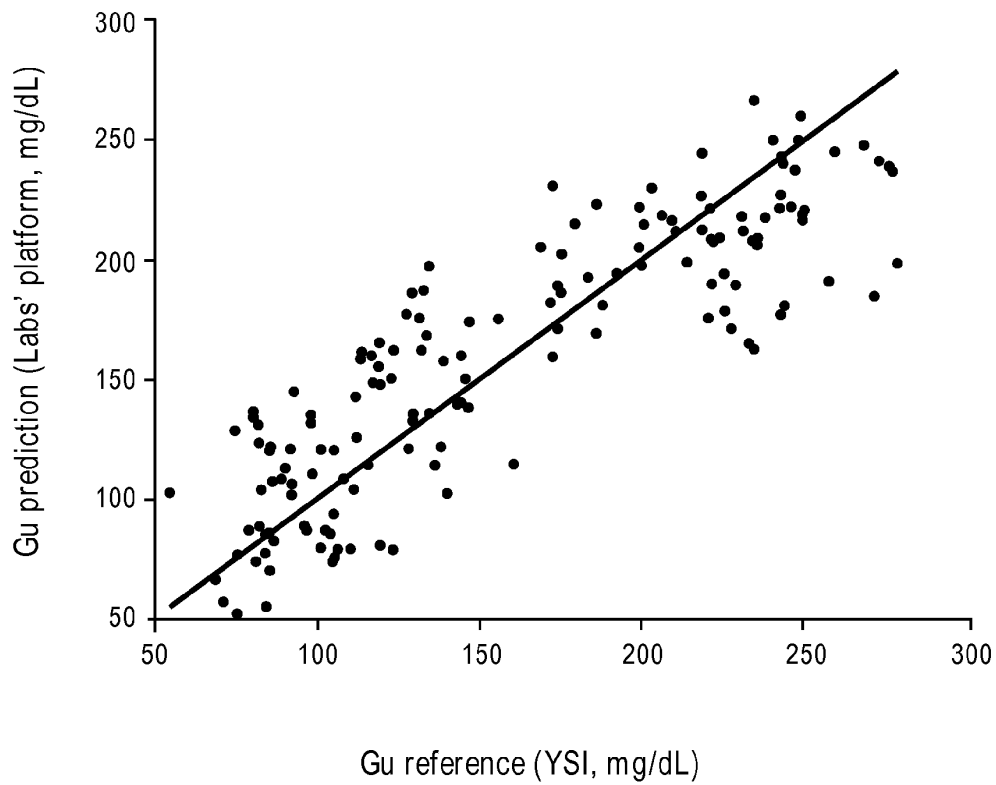
**FIG. 17**

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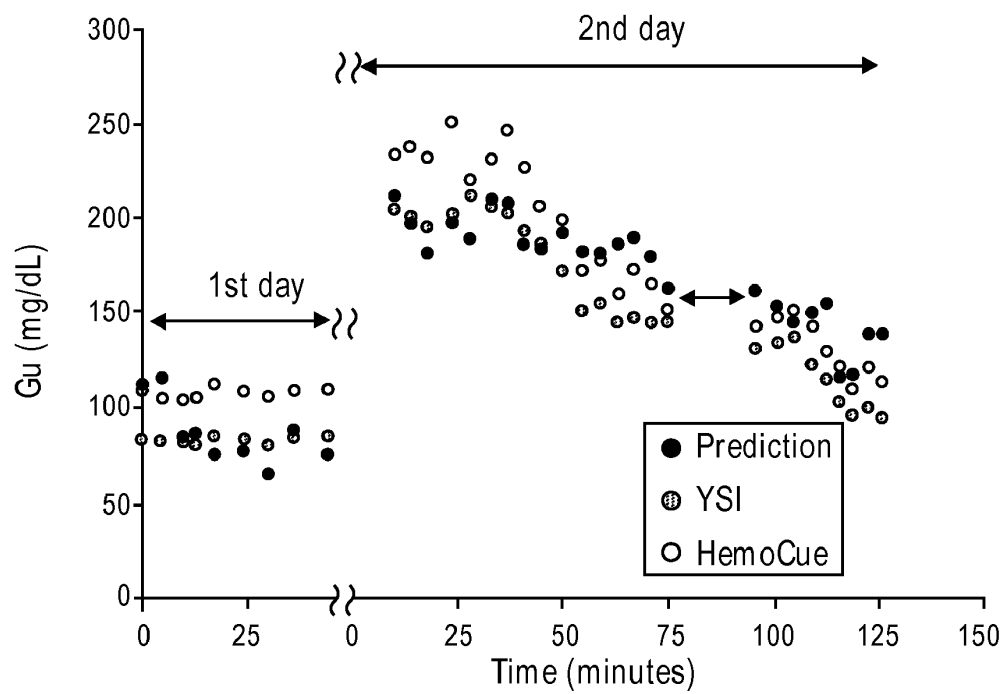
**FIG. 18**

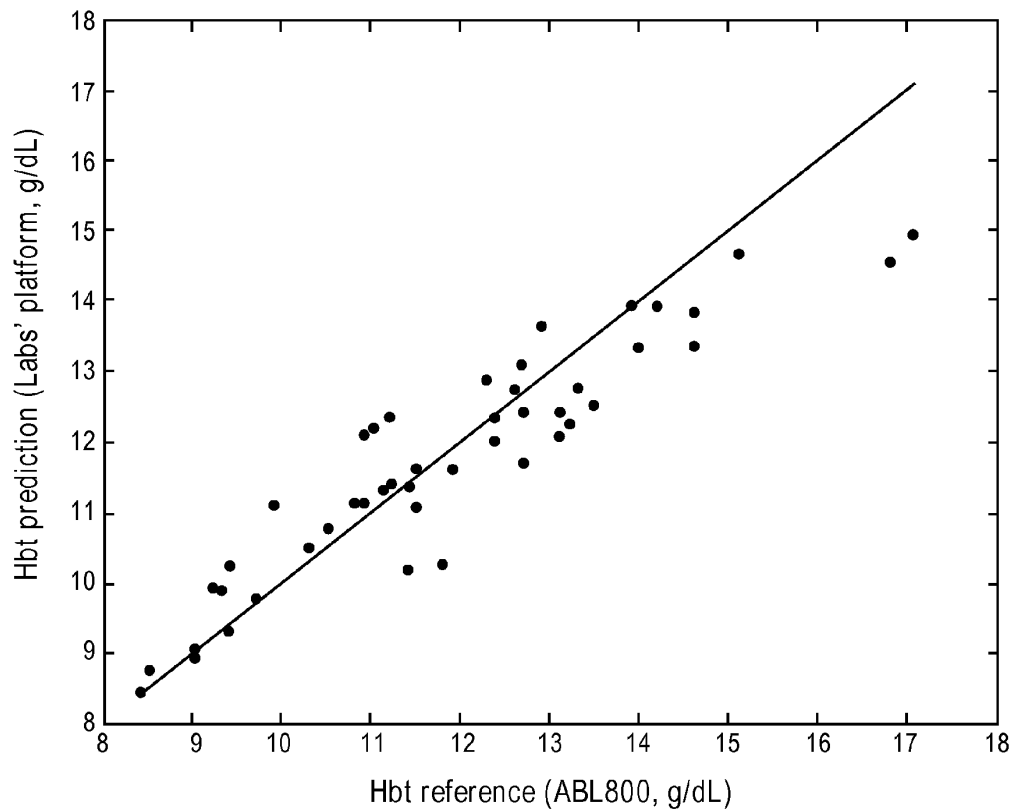
**FIG. 19**

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**FIG. 20**

**FIG. 21**



**FIG. 22**

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**MULTI-STREAM DATA COLLECTION  
SYSTEM FOR NONINVASIVE  
MEASUREMENT OF BLOOD  
CONSTITUENTS**

**RELATED APPLICATIONS**

**[0001]** This application claims the benefit of priority under 35 U.S.C. §119(e) of the following U.S. Provisional Patent Applications:

App. No.	Filing Date	Title	Attorney Docket
61/086,060	Aug. 4, 2008	Multi-Stream Data Collection System For Non-Invasive Measurement of Glucose and Other Analytes	MLHUM.002PR
61/086,108	Aug. 4, 2008	Multi-Stream Sensor Front Ends for Noninvasive Measurement of Glucose and Other Analytes	MLHUM.003PR
61/086,063	Aug. 4, 2008	Multi-Stream Detector For Noninvasive Measurement Of Glucose And Other Analytes	MLHUM.004PR
61/086,057	Aug. 4, 2008	Multi-Stream Emitter For Noninvasive Measurement Of Glucose And Other Analytes	MLHUM.005PR
61/091,732	Aug. 25, 2008	Sensor For Improving Measurement Of Blood Constituents	MLHUM.011PR

**[0002]** This application is related to the following U.S. patent application Ser. No.:

App. No.	Filing Date	Title	Attorney Docket
12/497,528	Jul. 2, 2009	Noise Shielding for Noninvasive Device	MLHUM.006A
12/497,523	Jul. 2, 2009	Contoured Protrusion for Improving Spectroscopic Measurement of Blood Constituents	MLHUM.007A
12/498,506	Jul. 2, 2009	Heat Sink for Noninvasive Medical Sensor	MLHUM.011A
Unknown	Herewith	Multi-Stream Sensor Front Ends for Non-Invasive Measurement of Blood Constituents	MLHUM.003A
Unknown	Herewith	Multi-Stream Sensor for Non-Invasive Measurement of Blood Constituents	MLHUM.004A
Unknown	Herewith	Multi-Stream Emitter for Non-Invasive Measurement of Blood Constituents	MLHUM.005A

**[0003]** The foregoing applications are hereby incorporated by reference in their entirety.

**BACKGROUND**

**[0004]** The standard of care in caregiver environments includes patient monitoring through spectroscopic analysis using, for example, a pulse oximeter. Devices capable of spectroscopic analysis generally include a light source(s) transmitting optical radiation into or reflecting off a measurement site, such as, body tissue carrying pulsing blood. After attenuation by tissue and fluids of the measurement site, a photodetection device(s) detects the attenuated light and outputs a detector signal(s) responsive to the detected attenuated light. A signal processing device(s) process the detector(s) signal(s) and outputs a measurement indicative of a blood

constituent of interest, such as glucose, oxygen, met hemoglobin, total hemoglobin, other physiological parameters, or other data or combinations of data useful in determining a state or trend of wellness of a patient.

**[0005]** In noninvasive devices and methods, a sensor is often adapted to position a finger proximate the light source and light detector. For example, noninvasive sensors often include a clothespin-shaped housing that includes a contoured bed conforming generally to the shape of a finger.

**SUMMARY**

**[0006]** This disclosure describes embodiments of noninvasive methods, devices, and systems for measuring a blood constituent or analyte, such as oxygen, carbon monoxide, methemoglobin, total hemoglobin, glucose, proteins, glucose, lipids, a percentage thereof (e.g., saturation) or for measuring many other physiologically relevant patient characteristics. These characteristics can relate, for example, to pulse rate, hydration, trending information and analysis, and the like.

**[0007]** In an embodiment, the system includes a noninvasive sensor and a patient monitor communicating with the noninvasive sensor. The non-invasive sensor may include different architectures to implement some or all of the disclosed features. In addition, an artisan will recognize that the non-invasive sensor may include or may be coupled to other com-

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ponents, such as a network interface, and the like. Moreover, the patient monitor may include a display device, a network interface communicating with any one or combination of a computer network, a handheld computing device, a mobile phone, the Internet, or the like. In addition, embodiments may include multiple optical sources that emit light at a plurality of wavelengths and that are arranged from the perspective of the light detector(s) as a point source.

**[0008]** In an embodiment, a noninvasive device is capable of producing a signal responsive to light attenuated by tissue at a measurement site. The device may comprise an optical source and a plurality of photodetectors. The optical source is configured to emit optical radiation at least at wavelengths between about 1600 nm and about 1700 nm. The photodetectors are configured to detect the optical radiation from said optical source after attenuation by the tissue of the measurement site and each output a respective signal stream responsive to the detected optical radiation.

**[0009]** In an embodiment, a noninvasive, physiological sensor is capable of outputting a signal responsive to a blood analyte present in a monitored patient. The sensor may comprise a sensor housing, an optical source, and photodetectors. The optical source is positioned by the housing with respect to a tissue site of a patient when said housing is applied to the patient. The photodetectors are positioned by the housing with respect to said tissue site when the housing is applied to the patient with a variation in path length among at least some of the photodetectors from the optical source. The photodetectors are configured to detect a sequence of optical radiation from the optical source after attenuation by tissue of the tissue site. The photodetectors may be each configured to output a respective signal stream responsive to the detected sequence of optical radiation. An output signal responsive to one or more of the signal streams is then usable to determine the blood analyte based at least in part on the variation in path length.

**[0010]** In an embodiment, a method of measuring an analyte based on multiple streams of optical radiation measured from a measurement site is provided. A sequence of optical radiation pulses is emitted to the measurement site. At a first location, a first stream of optical radiation is detected from the measurement site. At least at one additional location different from the first location, an additional stream of optical radiation is detected from the measurement site. An output measurement value indicative of the analyte is then determined based on the detected streams of optical radiation.

**[0011]** For purposes of summarizing the disclosure, certain aspects, advantages and novel features of the inventions have been described herein. It is to be understood that not necessarily all such advantages can be achieved in accordance with any particular embodiment of the inventions disclosed herein. Thus, the inventions disclosed herein can be embodied or carried out in a manner that achieves or optimizes one advantage or group of advantages as taught herein without necessarily achieving other advantages as can be taught or suggested herein.

#### BRIEF DESCRIPTION OF THE DRAWINGS

**[0012]** Throughout the drawings, reference numbers can be re-used to indicate correspondence between referenced elements. The drawings are provided to illustrate embodiments of the inventions described herein and not to limit the scope thereof.

**[0013]** FIG. 1 illustrates a block diagram of an example data collection system capable of noninvasively measuring one or more blood analytes in a monitored patient, according to an embodiment of the disclosure;

**[0014]** FIGS. 2A-2D illustrate an exemplary handheld monitor and an exemplary noninvasive optical sensor of the patient monitoring system of FIG. 1, according to embodiments of the disclosure;

**[0015]** FIGS. 3A-3C illustrate side and perspective views of an exemplary noninvasive sensor housing including a finger bed protrusion and heat sink, according to an embodiment of the disclosure;

**[0016]** FIG. 3D illustrates a side view of another example noninvasive sensor housing including a heat sink, according to an embodiment of the disclosure;

**[0017]** FIG. 3E illustrates a perspective view of an example noninvasive sensor detector shell including example detectors, according to an embodiment of the disclosure;

**[0018]** FIG. 3F illustrates a side view of an example noninvasive sensor housing including a finger bed protrusion and heat sink, according to an embodiment of the disclosure;

**[0019]** FIGS. 4A through 4C illustrate top elevation, side and top perspective views of an example protrusion, according to an embodiment of the disclosure;

**[0020]** FIG. 5 illustrates an example graph depicting possible effects of a protrusion on light transmittance, according to an embodiment of the disclosure;

**[0021]** FIGS. 6A through 6D illustrate perspective, front elevation, side and top views of another example protrusion, according to an embodiment of the disclosure;

**[0022]** FIG. 6E illustrates an example sensor incorporating the protrusion of FIGS. 6A through 6D, according to an embodiment of the disclosure;

**[0023]** FIGS. 7A through 7B illustrate example arrangements of conductive glass that may be employed in the system of FIG. 1, according to embodiments of the disclosure.

**[0024]** FIGS. 8A through 8D illustrate an example top elevation view, side views, and a bottom elevation view of the conductive glass that may be employed in the system of FIG. 1, according to embodiments of the disclosure;

**[0025]** FIG. 9 shows example comparative results obtained by an embodiment of a sensor;

**[0026]** FIGS. 10A and 10B illustrate comparative noise floors of various embodiments of the present disclosure;

**[0027]** FIG. 11A illustrates an exemplary emitter that may be employed in the sensor, according to an embodiment of the disclosure;

**[0028]** FIG. 11B illustrates a configuration of emitting optical radiation into a measurement site for measuring blood constituents, according to an embodiment of the disclosure;

**[0029]** FIG. 11C illustrates another exemplary emitter that may be employed in the sensor according to an embodiment of the disclosure;

**[0030]** FIG. 11D illustrates another exemplary emitter that may be employed in the sensor according to an embodiment of the disclosure.

**[0031]** FIG. 12A illustrates an example detector portion that may be employed in an embodiment of a sensor, according to an embodiment of the disclosure;

**[0032]** FIGS. 12B through 12D illustrate exemplary arrangements of detectors that may be employed in an embodiment of the sensor, according to some embodiments of the disclosure;



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[0033] FIGS. 12E through 12H illustrate exemplary structures of photodiodes that may be employed in embodiments of the detectors, according to some embodiments of the disclosure;

[0034] FIG. 13 illustrates an example multi-stream operation of the system of FIG. 1, according to an embodiment of the disclosure;

[0035] FIG. 14A illustrates another example detector portion having a partially cylindrical protrusion that can be employed in an embodiment of a sensor, according to an embodiment of the disclosure;

[0036] FIG. 14B depicts a front elevation view of the partially cylindrical protrusion of FIG. 14A;

[0037] FIGS. 14C through 14E illustrate embodiments of a detector submount;

[0038] FIGS. 14F through 14H illustrate embodiment of portions of a detector shell;

[0039] FIG. 14I illustrates a cutaway view of an embodiment of a sensor;

[0040] FIGS. 15A through 15F illustrate embodiments of sensors that include heat sink features;

[0041] FIGS. 15G and 15H illustrate embodiments of connector features that can be used with any of the sensors described herein;

[0042] FIG. 15I illustrates an exemplary architecture for a transimpedance-based front-end that may be employed in any of the sensors described herein;

[0043] FIG. 15J illustrates an exemplary noise model for configuring the transimpedance-based front-ends shown in FIG. 15I;

[0044] FIG. 15K shows different architectures and layouts for various embodiments of a sensor and its detectors;

[0045] FIG. 15L illustrates an exemplary architecture for a switched-capacitor-based front-end that may be employed in any of the sensors described herein;

[0046] FIGS. 16A and 16B illustrate embodiments of disposable optical sensors;

[0047] FIG. 17 illustrates an exploded view of certain components of an example sensor; and

[0048] FIGS. 18 through 22 illustrate various results obtained by an exemplary sensor of the disclosure.

#### DETAILED DESCRIPTION

[0049] The present disclosure generally relates to non-invasive medical devices. In the present disclosure, a sensor can measure various blood constituents or analytes noninvasively using multi-stream spectroscopy. In an embodiment, the multi-stream spectroscopy can employ visible, infrared and near infrared wavelengths. As disclosed herein, the sensor is capable of noninvasively measuring blood analytes or percentages thereof (e.g., saturation) based on various combinations of features and components.

[0050] The sensor can include photocommunicative components, such as an emitter, a detector, and other components. The emitter can include a plurality of sets of optical sources that, in an embodiment, are arranged together as a point source. The various optical sources can emit a sequence of optical radiation pulses at different wavelengths towards a measurement site, such as a patient's finger. Detectors can then detect optical radiation from the measurement site. The optical sources and optical radiation detectors can operate at any appropriate wavelength, including, as discussed herein, infrared, near infrared, visible light, and ultraviolet. In addition, the optical sources and optical radiation detectors can

operate at any appropriate wavelength, and such modifications to the embodiments desirable to operate at any such wavelength will be apparent to those skilled in the art.

[0051] In certain embodiments, multiple detectors are employed and arranged in a spatial geometry. This spatial geometry provides a diversity of path lengths among at least some of the detectors and allows for multiple bulk and pulsatile measurements that are robust. Each of the detectors can provide a respective output stream based on the detected optical radiation, or a sum of output streams can be provided from multiple detectors. In some embodiments, the sensor can also include other components, such as one or more heat sinks and one or more thermistors.

[0052] The sensor can be coupled to one or more monitors that process and/or display the sensor's output. The monitors can include various components, such as a sensor front end, a signal processor, a display, etc.

[0053] The sensor can be integrated with a monitor, for example, into a handheld unit including the sensor, a display and user controls. In other embodiments, the sensor can communicate with one or more processing devices. The communication can be via wire(s), cable(s), flex circuit(s), wireless technologies, or other suitable analog or digital communication methodologies and devices to perform those methodologies. Many of the foregoing arrangements allow the sensor to be attached to the measurement site while the device is attached elsewhere on a patient, such as the patient's arm, or placed at a location near the patient, such as a bed, shelf or table. The sensor or monitor can also provide outputs to a storage device or network interface.

[0054] Reference will now be made to the Figures to discuss embodiments of the present disclosure.

[0055] FIG. 1 illustrates an example of a data collection system 100. In certain embodiments, the data collection system 100 noninvasively measure a blood analyte, such as oxygen, carbon monoxide, methemoglobin, total hemoglobin, glucose, proteins, glucose, lipids, a percentage thereof (e.g., saturation) or for measuring many other physiologically relevant patient characteristics. The system 100 can also measure additional blood analytes and/or other physiological parameters useful in determining a state or trend of wellness of a patient.

[0056] The data collection system 100 can be capable of measuring optical radiation from the measurement site. For example, in some embodiments, the data collection system 100 can employ photodiodes defined in terms of area. In an embodiment, the area is from about 1 mm<sup>2</sup>-5 mm<sup>2</sup> (or higher) that are capable of detecting about 100 nanoamps (nA) or less of current resulting from measured light at full scale. In addition to having its ordinary meaning, the phrase "at full scale" can mean light saturation of a photodiode amplifier (not shown). Of course, as would be understood by a person of skill in the art from the present disclosure, various other sizes and types of photodiodes can be used with the embodiments of the present disclosure.

[0057] The data collection system 100 can measure a range of approximately about 2 nA to about 100 nA full scale. The data collection system 100 can also include sensor front-ends that are capable of processing and amplifying current from the detector(s) at signal-to-noise ratios (SNRs) of about 100 decibels (dB) or more, such as about 120 dB in order to measure various desired analytes. The data collection system 100 can operate with a lower SNR if less accuracy is desired for an analyte like glucose.

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[0058] The data collection system 100 can measure analyte concentrations, including glucose, at least in part by detecting light attenuated by a measurement site 102. The measurement site 102 can be any location on a patient's body, such as a finger, foot, ear lobe, or the like. For convenience, this disclosure is described primarily in the context of a finger measurement site 102. However, the features of the embodiments disclosed herein can be used with other measurement sites 102.

[0059] In the depicted embodiment, the system 100 includes an optional tissue thickness adjuster or tissue shaper 105, which can include one or more protrusions, bumps, lenses, or other suitable tissue-shaping mechanisms. In certain embodiments, the tissue shaper 105 is a flat or substantially flat surface that can be positioned proximate the measurement site 102 and that can apply sufficient pressure to cause the tissue of the measurement site 102 to be flat or substantially flat. In other embodiments, the tissue shaper 105 is a convex or substantially convex surface with respect to the measurement site 102. Many other configurations of the tissue shaper 105 are possible. Advantageously, in certain embodiments, the tissue shaper 105 reduces thickness of the measurement site 102 while preventing or reducing occlusion at the measurement site 102. Reducing thickness of the site can advantageously reduce the amount of attenuation of the light because there is less tissue through which the light must travel. Shaping the tissue in to a convex (or alternatively concave) surface can also provide more surface area from which light can be detected.

[0060] The embodiment of the data collection system 100 shown also includes an optional noise shield 103. In an embodiment, the noise shield 103 can be advantageously adapted to reduce electromagnetic noise while increasing the transmittance of light from the measurement site 102 to one or more detectors 106 (described below). For example, the noise shield 103 can advantageously include a conductive coated glass or metal grid electrically communicating with one or more other shields of the sensor 101 or electrically grounded. In an embodiment where the noise shield 103 includes conductive coated glass, the coating can advantageously include indium tin oxide. In an embodiment, the indium tin oxide includes a surface resistivity ranging from approximately 30 ohms per square inch to about 500 ohms per square inch. In an embodiment, the resistivity is approximately 30, 200, or 500 ohms per square inch. As would be understood by a person of skill in the art from the present disclosure, other resistivities can also be used which are less than about 30 ohms or more than about 500 ohms. Other conductive materials transparent or substantially transparent to light can be used instead.

[0061] In some embodiments, the measurement site 102 is located somewhere along a non-dominant arm or a non-dominant hand, e.g., a right-handed person's left arm or left hand. In some patients, the non-dominant arm or hand can have less musculature and higher fat content, which can result in less water content in that tissue of the patient. Tissue having less water content can provide less interference with the particular wavelengths that are absorbed in a useful manner by blood analytes like glucose. Accordingly, in some embodiments, the data collection system 100 can be used on a person's non-dominant hand or arm.

[0062] The data collection system 100 can include a sensor 101 (or multiple sensors) that is coupled to a processing device or physiological monitor 109. In an embodiment, the sensor 101 and the monitor 109 are integrated together into a

single unit. In another embodiment, the sensor 101 and the monitor 109 are separate from each other and communicate one with another in any suitable manner, such as via a wired or wireless connection. The sensor 101 and monitor 109 can be attachable and detachable from each other for the convenience of the user or caregiver, for ease of storage, sterility issues, or the like. The sensor 101 and the monitor 109 will now be further described.

[0063] In the depicted embodiment shown in FIG. 1, the sensor 101 includes an emitter 104, a tissue shaper 105, a set of detectors 106, and a front-end interface 108. The emitter 104 can serve as the source of optical radiation transmitted towards measurement site 102. As will be described in further detail below, the emitter 104 can include one or more sources of optical radiation, such as LEDs, laser diodes, incandescent bulbs with appropriate frequency-selective filters, combinations of the same, or the like. In an embodiment, the emitter 104 includes sets of optical sources that are capable of emitting visible and near-infrared optical radiation.

[0064] In some embodiments, the emitter 104 is used as a point optical source, and thus, the one or more optical sources of the emitter 104 can be located within a close distance to each other, such as within about a 2 mm to about 4 mm. The emitters 104 can be arranged in an array, such as is described in U.S. Publication No. 2006/0211924, filed Sep. 21, 2006, titled "Multiple Wavelength Sensor Emitters," the disclosure of which is hereby incorporated by reference in its entirety. In particular, the emitters 104 can be arranged at least in part as described in paragraphs [0061] through [0068] of the aforementioned publication, which paragraphs are hereby incorporated specifically by reference. Other relative spatial relationships can be used to arrange the emitters 104.

[0065] For analytes like glucose, currently available non-invasive techniques often attempt to employ light near the water absorbance minima at or about 1600 nm. Typically, these devices and methods employ a single wavelength or single band of wavelengths at or about 1600 nm. However, to date, these techniques have been unable to adequately consistently measure analytes like glucose based on spectroscopy.

[0066] In contrast, the emitter 104 of the data collection system 100 can emit, in certain embodiments, combinations of optical radiation in various bands of interest. For example, in some embodiments, for analytes like glucose, the emitter 104 can emit optical radiation at three (3) or more wavelengths between about 1600 nm to about 1700 nm. In particular, the emitter 104 can emit optical radiation at or about 1610 nm, about 1640 nm, and about 1665 nm. In some circumstances, the use of three wavelengths within about 1600 nm to about 1700 nm enable sufficient SNRs of about 100 dB, which can result in a measurement accuracy of about 20 mg/dL or better for analytes like glucose.

[0067] In other embodiments, the emitter 104 can use two (2) wavelengths within about 1600 nm to about 1700 nm to advantageously enable SNRs of about 85 dB, which can result in a measurement accuracy of about 25-30 mg/dL or better for analytes like glucose. Furthermore, in some embodiments, the emitter 104 can emit light at wavelengths above about 1670 nm. Measurements at these wavelengths can be advantageously used to compensate or confirm the contribution of protein, water, and other non-hemoglobin species exhibited in measurements for analytes like glucose conducted between about 1600 nm and about 1700 nm. Of course, other wavelengths and combinations of wavelengths

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can be used to measure analytes and/or to distinguish other types of tissue, fluids, tissue properties, fluid properties, combinations of the same or the like.

**[0068]** For example, the emitter **104** can emit optical radiation across other spectra for other analytes. In particular, the emitter **104** can employ light wavelengths to measure various blood analytes or percentages (e.g., saturation) thereof. For example, in one embodiment, the emitter **104** can emit optical radiation in the form of pulses at wavelengths about 905 nm, about 1050 nm, about 1200 nm, about 1300 nm, about 1330 nm, about 1610 nm, about 1640 nm, and about 1665 nm. In another embodiment, the emitter **104** can emit optical radiation ranging from about 860 nm to about 950 nm, about 950 nm to about 1100 nm, about 1100 nm to about 1270 nm, about 1250 nm to about 1350 nm, about 1300 nm to about 1360 nm, and about 1590 nm to about 1700 nm. Of course, the emitter **104** can transmit any of a variety of wavelengths of visible or near-infrared optical radiation.

**[0069]** Due to the different responses of analytes to the different wavelengths, certain embodiments of the data collection system **100** can advantageously use the measurements at these different wavelengths to improve the accuracy of measurements. For example, the measurements of water from visible and infrared light can be used to compensate for water absorbance that is exhibited in the near-infrared wavelengths.

**[0070]** As briefly described above, the emitter **104** can include sets of light-emitting diodes (LEDs) as its optical source. The emitter **104** can use one or more top-emitting LEDs. In particular, in some embodiments, the emitter **104** can include top-emitting LEDs emitting light at about 850 nm to 1350 nm.

**[0071]** The emitter **104** can also use super luminescent LEDs (SLEDs) or side-emitting LEDs. In some embodiments, the emitter **104** can employ SLEDs or side-emitting LEDs to emit optical radiation at about 1600 nm to about 1800 nm. Emitter **104** can use SLEDs or side-emitting LEDs to transmit near infrared optical radiation because these types of sources can transmit at high power or relatively high power, e.g., about 40 mW to about 100 mW. This higher power capability can be useful to compensate or overcome the greater attenuation of these wavelengths of light in tissue and water. For example, the higher power emission can effectively compensate and/or normalize the absorption signal for light in the mentioned wavelengths to be similar in amplitude and/or effect as other wavelengths that can be detected by one or more photodetectors after absorption. However, the embodiments of the present disclosure do not necessarily require the use of high power optical sources. For example, some embodiments may be configured to measure analytes, such as total hemoglobin (tHb), oxygen saturation (SpO<sub>2</sub>), carboxyhemoglobin, methemoglobin, etc., without the use of high power optical sources like side emitting LEDs. Instead, such embodiments may employ other types of optical sources, such as top emitting LEDs. Alternatively, the emitter **104** can use other types of sources of optical radiation, such as a laser diode, to emit near-infrared light into the measurement site **102**.

**[0072]** In addition, in some embodiments, in order to assist in achieving a comparative balance of desired power output between the LEDs, some of the LEDs in the emitter **104** can have a filter or covering that reduces and/or cleans the optical radiation from particular LEDs or groups of LEDs. For example, since some wavelengths of light can penetrate through tissue relatively well, LEDs, such as some or all of the

top-emitting LEDs can use a filter or covering, such as a cap or painted dye. This can be useful in allowing the emitter **104** to use LEDs with a higher output and/or to equalize intensity of LEDs.

**[0073]** The data collection system **100** also includes a driver **111** that drives the emitter **104**. The driver **111** can be a circuit or the like that is controlled by the monitor **109**. For example, the driver **111** can provide pulses of current to the emitter **104**. In an embodiment, the driver **111** drives the emitter **104** in a progressive fashion, such as in an alternating manner. The driver **111** can drive the emitter **104** with a series of pulses of about 1 milliwatt (mW) for some wavelengths that can penetrate tissue relatively well and from about 40 mW to about 100 mW for other wavelengths that tend to be significantly absorbed in tissue. A wide variety of other driving powers and driving methodologies can be used in various embodiments.

**[0074]** The driver **111** can be synchronized with other parts of the sensor **101** and can minimize or reduce jitter in the timing of pulses of optical radiation emitted from the emitter **104**. In some embodiments, the driver **111** is capable of driving the emitter **104** to emit optical radiation in a pattern that varies by less than about 10 parts-per-million.

**[0075]** The detectors **106** capture and measure light from the measurement site **102**. For example, the detectors **106** can capture and measure light transmitted from the emitter **104** that has been attenuated or reflected from the tissue in the measurement site **102**. The detectors **106** can output a detector signal **107** responsive to the light captured or measured. The detectors **106** can be implemented using one or more photodiodes, phototransistors, or the like.

**[0076]** In addition, the detectors **106** can be arranged with a spatial configuration to provide a variation of path lengths among at least some of the detectors **106**. That is, some of the detectors **106** can have the substantially, or from the perspective of the processing algorithm, effectively, the same path length from the emitter **104**. However, according to an embodiment, at least some of the detectors **106** can have a different path length from the emitter **104** relative to other of the detectors **106**. Variations in path lengths can be helpful in allowing the use of a bulk signal stream from the detectors **106**. In some embodiments, the detectors **106** may employ a linear spacing, a logarithmic spacing, or a two or three dimensional matrix of spacing, or any other spacing scheme in order to provide an appropriate variation in path lengths.

**[0077]** The front end interface **108** provides an interface that adapts the output of the detectors **106**, which is responsive to desired physiological parameters. For example, the front end interface **108** can adapt a signal **107** received from one or more of the detectors **106** into a form that can be processed by the monitor **109**, for example, by a signal processor **110** in the monitor **109**. The front end interface **108** can have its components assembled in the sensor **101**, in the monitor **109**, in connecting cabling (if used), combinations of the same, or the like. The location of the front end interface **108** can be chosen based on various factors including space desired for components, desired noise reductions or limits, desired heat reductions or limits, and the like.

**[0078]** The front end interface **108** can be coupled to the detectors **106** and to the signal processor **110** using a bus, wire, electrical or optical cable, flex circuit, or some other form of signal connection. The front end interface **108** can also be at least partially integrated with various components, such as the detectors **106**. For example, the front end interface

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**108** can include one or more integrated circuits that are on the same circuit board as the detectors **106**. Other configurations can also be used.

**[0079]** The front end interface **108** can be implemented using one or more amplifiers, such as transimpedance amplifiers, that are coupled to one or more analog to digital converters (ADCs) (which can be in the monitor **109**), such as a sigma-delta ADC. A transimpedance-based front end interface **108** can employ single-ended circuitry, differential circuitry, and/or a hybrid configuration. A transimpedance-based front end interface **108** can be useful for its sampling rate capability and freedom in modulation/demodulation algorithms. For example, this type of front end interface **108** can advantageously facilitate the sampling of the ADCs being synchronized with the pulses emitted from the emitter **104**.

**[0080]** The ADC or ADCs can provide one or more outputs into multiple channels of digital information for processing by the signal processor **110** of the monitor **109**. Each channel can correspond to a signal output from a detector **106**.

**[0081]** In some embodiments, a programmable gain amplifier (PGA) can be used in combination with a transimpedance-based front end interface **108**. For example, the output of a transimpedance-based front end interface **108** can be output to a PGA that is coupled with an ADC in the monitor **109**. A PGA can be useful in order to provide another level of amplification and control of the stream of signals from the detectors **106**. Alternatively, the PGA and ADC components can be integrated with the transimpedance-based front end interface **108** in the sensor **101**.

**[0082]** In another embodiment, the front end interface **108** can be implemented using switched-capacitor circuits. A switched-capacitor-based front end interface **108** can be useful for, in certain embodiments, its resistor-free design and analog averaging properties. In addition, a switched-capacitor-based front end interface **108** can be useful because it can provide a digital signal to the signal processor **110** in the monitor **109**.

**[0083]** As shown in FIG. 1, the monitor **109** can include the signal processor **110** and a user interface, such as a display **112**. The monitor **109** can also include optional outputs alone or in combination with the display **112**, such as a storage device **114** and a network interface **116**. In an embodiment, the signal processor **110** includes processing logic that determines measurements for desired analytes, such as glucose, based on the signals received from the detectors **106**. The signal processor **110** can be implemented using one or more microprocessors or subprocessors (e.g., cores), digital signal processors, application specific integrated circuits (ASICs), field programmable gate arrays (FPGAs), combinations of the same, and the like.

**[0084]** The signal processor **110** can provide various signals that control the operation of the sensor **101**. For example, the signal processor **110** can provide an emitter control signal to the driver **111**. This control signal can be useful in order to synchronize, minimize, or reduce jitter in the timing of pulses emitted from the emitter **104**. Accordingly, this control signal can be useful in order to cause optical radiation pulses emitted from the emitter **104** to follow a precise timing and consistent pattern. For example, when a transimpedance-based front end interface **108** is used, the control signal from the signal processor **110** can provide synchronization with the ADC in order to avoid aliasing, cross-talk, and the like. As also shown, an optional memory **113** can be included in the front-end interface **108** and/or in the signal processor **110**. This memory

**113** can serve as a buffer or storage location for the front-end interface **108** and/or the signal processor **110**, among other uses.

**[0085]** The user interface **112** can provide an output, e.g., on a display, for presentation to a user of the data collection system **100**. The user interface **112** can be implemented as a touch-screen display, an LCD display, an organic LED display, or the like. In addition, the user interface **112** can be manipulated to allow for measurement on the non-dominant side of patient. For example, the user interface **112** can include a flip screen, a screen that can be moved from one side to another on the monitor **109**, or can include an ability to reorient its display indicia responsive to user input or device orientation. In alternative embodiments, the data collection system **100** can be provided without a user interface **112** and can simply provide an output signal to a separate display or system.

**[0086]** A storage device **114** and a network interface **116** represent other optional output connections that can be included in the monitor **109**. The storage device **114** can include any computer-readable medium, such as a memory device, hard disk storage, EEPROM, flash drive, or the like. The various software and/or firmware applications can be stored in the storage device **114**, which can be executed by the signal processor **110** or another processor of the monitor **109**. The network interface **116** can be a serial bus port (RS-232/RS-485), a Universal Serial Bus (USB) port, an Ethernet port, a wireless interface (e.g., WiFi such as any 802.1x interface, including an internal wireless card), or other suitable communication device(s) that allows the monitor **109** to communicate and share data with other devices. The monitor **109** can also include various other components not shown, such as a microprocessor, graphics processor, or controller to output the user interface **112**, to control data communications, to compute data trending, or to perform other operations.

**[0087]** Although not shown in the depicted embodiment, the data collection system **100** can include various other components or can be configured in different ways. For example, the sensor **101** can have both the emitter **104** and detectors **106** on the same side of the measurement site **102** and use reflectance to measure analytes. The data collection system **100** can also include a sensor that measures the power of light emitted from the emitter **104**.

**[0088]** FIGS. 2A through 2D illustrate example monitoring devices **200** in which the data collection system **100** can be housed. Advantageously, in certain embodiments, some or all of the example monitoring devices **200** shown can have a shape and size that allows a user to operate it with a single hand or attach it, for example, to a patient's body or limb. Although several examples are shown, many other monitoring device configurations can be used to house the data collection system **100**. In addition, certain of the features of the monitoring devices **200** shown in FIGS. 2A through 2D can be combined with features of the other monitoring devices **200** shown.

**[0089]** Referring specifically to FIG. 2A, an example monitoring device **200A** is shown, in which a sensor **201a** and a monitor **209a** are integrated into a single unit. The monitoring device **200A** shown is a handheld or portable device that can measure glucose and other analytes in a patient's finger. The sensor **201a** includes an emitter shell **204a** and a detector shell **206a**. The depicted embodiment of the monitoring device **200A** also includes various control buttons **208a** and a display **210a**.

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[0090] The sensor **201a** can be constructed of white material used for reflective purposes (such as white silicone or plastic), which can increase the usable signal at the detector **106** by forcing light back into the sensor **201a**. Pads in the emitter shell **204a** and the detector shell **206a** can contain separated windows to prevent or reduce mixing of light signals, for example, from distinct quadrants on a patient's finger. In addition, these pads can be made of a relatively soft material, such as a gel or foam, in order to conform to the shape, for example, of a patient's finger. The emitter shell **204a** and the detector shell **206a** can also include absorbing black or grey material portions to prevent or reduce ambient light from entering into the sensor **201a**.

[0091] In some embodiments, some or all portions of the emitter shell **204a** and/or detector shell **206a** can be detachable and/or disposable. For example, some or all portions of the shells **204a** and **206a** can be removable pieces. The removability of the shells **204a** and **206a** can be useful for sanitary purposes or for sizing the sensor **201a** to different patients. The monitor **209a** can include a fitting, slot, magnet, or other connecting mechanism to allow the sensor **201c** to be removably attached to the monitor **209a**.

[0092] The monitoring device **200a** also includes optional control buttons **208a** and a display **210a** that can allow the user to control the operation of the device. For example, a user can operate the control buttons **208a** to view one or more measurements of various analytes, such as glucose. In addition, the user can operate the control buttons **208a** to view other forms of information, such as graphs, histograms, measurement data, trend measurement data, parameter combination views, wellness indications, and the like. Many parameters, trends, alarms and parameter displays could be output to the display **210a**, such as those that are commercially available through a wide variety of noninvasive monitoring devices from Masimo® Corporation of Irvine, Calif.

[0093] Furthermore, the controls **208a** and/or display **210a** can provide functionality for the user to manipulate settings of the monitoring device **200a**, such as alarm settings, emitter settings, detector settings, and the like. The monitoring device **200a** can employ any of a variety of user interface designs, such as frames, menus, touch-screens, and any type of button.

[0094] FIG. 2B illustrates another example of a monitoring device **200B**. In the depicted embodiment, the monitoring device **200B** includes a finger clip sensor **201b** connected to a monitor **209b** via a cable **212**. In the embodiment shown, the monitor **209b** includes a display **210b**, control buttons **208b** and a power button. Moreover, the monitor **209b** can advantageously include electronic processing, signal processing, and data storage devices capable of receiving signal data from said sensor **201b**, processing the signal data to determine one or more output measurement values indicative of one or more physiological parameters of a monitored patient, and displaying the measurement values, trends of the measurement values, combinations of measurement values, and the like.

[0095] The cable **212** connecting the sensor **201b** and the monitor **209b** can be implemented using one or more wires, optical fiber, flex circuits, or the like. In some embodiments, the cable **212** can employ twisted pairs of conductors in order to minimize or reduce cross-talk of data transmitted from the sensor **201b** to the monitor **209b**. Various lengths of the cable **212** can be employed to allow for separation between the sensor **201b** and the monitor **209b**. The cable **212** can be fitted with a connector (male or female) on either end of the cable **212** so that the sensor **201b** and the monitor **209b** can be

connected and disconnected from each other. Alternatively, the sensor **201b** and the monitor **209b** can be coupled together via a wireless communication link, such as an infrared link, radio frequency channel, or any other wireless communication protocol and channel.

[0096] The monitor **209b** can be attached to the patient. For example, the monitor **209b** can include a belt clip or straps (see, e.g., FIG. 2C) that facilitate attachment to a patient's belt, arm, leg, or the like. The monitor **209b** can also include a fitting, slot, magnet, LEMO snap-click connector, or other connecting mechanism to allow the cable **212** and sensor **201b** to be attached to the monitor **209b**.

[0097] The monitor **209b** can also include other components, such as a speaker, power button, removable storage or memory (e.g., a flash card slot), an AC power port, and one or more network interfaces, such as a universal serial bus interface or an Ethernet port. For example, the monitor **209b** can include a display **210b** that can indicate a measurement for glucose, for example, in mg/dL. Other analytes and forms of display can also appear on the monitor **209b**.

[0098] In addition, although a single sensor **201b** with a single monitor **209b** is shown, different combinations of sensors and device pairings can be implemented. For example, multiple sensors can be provided for a plurality of differing patient types or measurement sites or even patient fingers.

[0099] FIG. 2C illustrates yet another example of monitoring device **200C** that can house the data collection system **100**. Like the monitoring device **200B**, the monitoring device **200C** includes a finger clip sensor **201c** connected to a monitor **209c** via a cable **212**. The cable **212** can have all of the features described above with respect to FIG. 2B. The monitor **209c** can include all of the features of the monitor **200B** described above. For example, the monitor **209c** includes buttons **208c** and a display **210c**. The monitor **209c** shown also includes straps **214c** that allow the monitor **209c** to be attached to a patient's limb or the like.

[0100] FIG. 2D illustrates yet another example of monitoring device **200D** that can house the data collection system **100**. Like the monitoring devices **200B** and **200C**, the monitoring device **200D** includes a finger clip sensor **201d** connected to a monitor **209d** via a cable **212**. The cable **212** can have all of the features described above with respect to FIG. 2B. In addition to having some or all of the features described above with respect to FIGS. 2B and 2C, the monitoring device **200D** includes an optional universal serial bus (USB) port **216** and an Ethernet port **218**. The USB port **216** and the Ethernet port **218** can be used, for example, to transfer information between the monitor **209d** and a computer (not shown) via a cable. Software stored on the computer can provide functionality for a user to, for example, view physiological data and trends, adjust settings and download firmware updates to the monitor **209b**, and perform a variety of other functions. The USB port **216** and the Ethernet port **218** can be included with the other monitoring devices **200A**, **200B**, and **200C** described above.

[0101] FIGS. 3A through 3C illustrate more detailed examples of embodiments of a sensor **301a**. The sensor **301a** shown can include all of the features of the sensors **100** and **200** described above.

[0102] Referring to FIG. 3A, the sensor **301a** in the depicted embodiment is a clothespin-shaped clip sensor that includes an enclosure **302a** for receiving a patient's finger. The enclosure **302a** is formed by an upper section or emitter shell **304a**, which is pivotably connected with a lower section

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or detector shell **306a**. The emitter shell **304a** can be biased with the detector shell **306a** to close together around a pivot point **303a** and thereby sandwich finger tissue between the emitter and detector shells **304a**, **306a**.

**[0103]** In an embodiment, the pivot point **303a** advantageously includes a pivot capable of adjusting the relationship between the emitter and detector shells **304a**, **306a** to effectively level the sections when applied to a tissue site. In another embodiment, the sensor **301a** includes some or all features of the finger clip described in U.S. Publication No. 2006/0211924, incorporated above, such as a spring that causes finger clip forces to be distributed along the finger. Paragraphs [0096] through [0105], which describe this feature, are hereby specifically incorporated by reference.

**[0104]** The emitter shell **304a** can position and house various emitter components of the sensor **301a**. It can be constructed of reflective material (e.g., white silicone or plastic) and/or can be metallic or include metalized plastic (e.g., including carbon and aluminum) to possibly serve as a heat sink. The emitter shell **304a** can also include absorbing opaque material, such as, for example, black or grey colored material, at various areas, such as on one or more flaps **307a**, to reduce ambient light entering the sensor **301a**.

**[0105]** The detector shell **306a** can position and house one or more detector portions of the sensor **301a**. The detector shell **306a** can be constructed of reflective material, such as white silicone or plastic. As noted, such materials can increase the usable signal at a detector by forcing light back into the tissue and measurement site (see FIG. 1). The detector shell **306a** can also include absorbing opaque material at various areas, such as lower area **308a**, to reduce ambient light entering the sensor **301a**.

**[0106]** Referring to FIGS. 3B and 3C, an example of finger bed **310** is shown in the sensor **301b**. The finger bed **310** includes a generally curved surface shaped generally to receive tissue, such as a human digit. The finger bed **310** includes one or more ridges or channels **314**. Each of the ridges **314** has a generally convex shape that can facilitate increasing traction or gripping of the patient's finger to the finger bed. Advantageously, the ridges **314** can improve the accuracy of spectroscopic analysis in certain embodiments by reducing noise that can result from a measurement site moving or shaking loose inside of the sensor **301a**. The ridges **314** can be made from reflective or opaque materials in some embodiments to further increase SNR. In other implementations, other surface shapes can be used, such as, for example, generally flat, concave, or convex finger beds **310**.

**[0107]** Finger bed **310** can also include an embodiment of a tissue thickness adjuster or protrusion **305**. The protrusion **305** includes a measurement site contact area **370** (see FIG. 3C) that can contact body tissue of a measurement site. The protrusion **305** can be removed from or integrated with the finger bed **310**. Interchangeable, different shaped protrusions **305** can also be provided, which can correspond to different finger shapes, characteristics, opacity, sizes, or the like.

**[0108]** Referring specifically to FIG. 3C, the contact area **370** of the protrusion **305** can include openings or windows **320**, **321**, **322**, and **323**. When light from a measurement site passes through the windows **320**, **321**, **322**, and **323**, the light can reach one or more photodetectors (see FIG. 3E). In an embodiment, the windows **320**, **321**, **322**, and **323** mirror specific detector placements layouts such that light can impinge through the protrusion **305** onto the photodetectors. Any number of windows **320**, **321**, **322**, and **323** can be

employed in the protrusion **305** to allow light to pass from the measurement site to the photodetectors.

**[0109]** The windows **320**, **321**, **322**, and **323** can also include shielding, such as an embedded grid of wiring or a conductive glass coating, to reduce noise from ambient light or other electromagnetic noise. The windows **320**, **321**, **322**, and **323** can be made from materials, such as plastic or glass. In some embodiments, the windows **320**, **321**, **322**, and **323** can be constructed from conductive glass, such as indium tin oxide (ITO) coated glass. Conductive glass can be useful because its shielding is transparent, and thus allows for a larger aperture versus a window with an embedded grid of wiring. In addition, in certain embodiments, the conductive glass does not need openings in its shielding (since it is transparent), which enhances its shielding performance. For example, some embodiments that employ the conductive glass can attain up to an about 40% to about 50% greater signal than non-conductive glass with a shielding grid. In addition, in some embodiments, conductive glass can be useful for shielding noise from a greater variety of directions than non-conductive glass with a shielding grid.

**[0110]** Turning to FIG. 3B, the sensor **301a** can also include a shielding **315a**, such as a metal cage, box, metal sheet, perforated metal sheet, a metal layer on a non-metal material, or the like. The shielding **315a** is provided in the depicted embodiment below or embedded within the protrusion **305** to reduce noise. The shielding **315a** can be constructed from a conductive material, such as copper. The shielding **315a** can include one or more openings or windows (not shown). The windows can be made from glass or plastic to thereby allow light that has passed through the windows **320**, **321**, **322**, and **323** on an external surface of the protrusion **305** (see FIG. 3C) to pass through to one or more photodetectors that can be enclosed or provided below (see FIG. 3E).

**[0111]** In some embodiments, the shielding cage for shielding **315a** can be constructed in a single manufactured component with or without the use of conductive glass. This form of construction may be useful in order to reduce costs of manufacture as well as assist in quality control of the components. Furthermore, the shielding cage can also be used to house various other components, such as sigma delta components for various embodiments of front end interfaces **108**.

**[0112]** In an embodiment, the photodetectors can be positioned within or directly beneath the protrusion **305** (see FIG. 3E). In such cases, the mean optical path length from the emitters to the detectors can be reduced and the accuracy of blood analyte measurement can increase. For example, in one embodiment, a convex bump of about 1 mm to about 3 mm in height and about 10 mm<sup>2</sup> to about 60 mm<sup>2</sup> was found to help signal strength by about an order of magnitude versus other shapes. Of course other dimensions and sizes can be employed in other embodiments. Depending on the properties desired, the length, width, and height of the protrusion **305** can be selected. In making such determinations, consideration can be made of protrusion's **305** effect on blood flow at the measurement site and mean path length for optical radiation passing through openings **320**, **321**, **322**, and **323**. Patient comfort can also be considered in determining the size and shape of the protrusion.

**[0113]** In an embodiment, the protrusion **305** can include a pliant material, including soft plastic or rubber, which can somewhat conform to the shape of a measurement site. Pliant materials can improve patient comfort and tactility by conforming the measurement site contact area **370** to the mea-

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surement site. Additionally, pliant materials can minimize or reduce noise, such as ambient light. Alternatively, the protrusion 305 can be made from a rigid material, such as hard plastic or metal.

[0114] Rigid materials can improve measurement accuracy of a blood analyte by conforming the measurement site to the contact area 370. The contact area 370 can be an ideal shape for improving accuracy or reducing noise. Selecting a material for the protrusion 305 can include consideration of materials that do not significantly alter blood flow at the measurement site. The protrusion 305 and the contact area 370 can include a combination of materials with various characteristics.

[0115] The contact area 370 serves as a contact surface for the measurement site. For example, in some embodiments, the contact area 370 can be shaped for contact with a patient's finger. Accordingly, the contact area 370 can be sized and shaped for different sizes of fingers. The contact area 370 can be constructed of different materials for reflective purposes as well as for the comfort of the patient. For example, the contact area 370 can be constructed from materials having various hardness and textures, such as plastic, gel, foam, and the like.

[0116] The formulas and analysis that follow with respect to FIG. 5 provide insight into how selecting these variables can alter transmittance and intensity gain of optical radiation that has been applied to the measurement site. These examples do not limit the scope of this disclosure.

[0117] Referring to FIG. 5, a plot 500 is shown that illustrates examples of effects of embodiments of the protrusion 305 on the SNR at various wavelengths of light. As described above, the protrusion 305 can assist in conforming the tissue and effectively reduce its mean path length. In some instances, this effect by the protrusion 305 can have significant impact on increasing the SNR.

[0118] According to the Beer Lambert law, a transmittance of light (I) can be expressed as follows:  $I = I_0 * e^{-m * b * c}$ , where  $I_0$  is the initial power of light being transmitted, m is the path length traveled by the light, and the component "b\*c" corresponds to the bulk absorption of the light at a specific wavelength of light. For light at about 1600 nm to about 1700 nm, for example, the bulk absorption component is generally around  $0.7 \text{ mm}^{-1}$ . Assuming a typical finger thickness of about 12 mm and a mean path length of 20 mm due to tissue scattering, then  $I = I_0 * e^{(-20 * 0.7)}$ .

[0119] In an embodiment where the protrusion 305 is a convex bump, the thickness of the finger can be reduced to 10 mm (from 12 mm) for some fingers and the effective light mean path is reduced to about 16.6 mm from 20 mm (see box 510). This results in a new transmittance,  $I_1 = I_0 * e^{(-16.6 * 0.7)}$ . A curve for a typical finger (having a mean path length of 20 mm) across various wavelengths is shown in the plot 500 of FIG. 5. The plot 500 illustrates potential effects of the protrusion 305 on the transmittance. As illustrated, comparing I and  $I_1$  results in an intensity gain of  $e^{(-16.6 * 0.7) / e^{(-20 * 0.7)}}$ , which is about a 10 times increase for light in the about 1600 nm to about 1700 nm range. Such an increase can affect the SNR at which the sensor can operate. The foregoing gains can be due at least in part to the about 1600 nm to about 1700 nm range having high values in bulk absorptions (water, protein, and the like), e.g., about  $0.7 \text{ mm}^{-1}$ . The plot 500 also shows improvements in the visible/near-infrared range (about 600 nm to about 1300 nm).

[0120] Turning again to FIGS. 3A through 3C, an example heat sink 350a is also shown. The heat sink 350a can be

attached to, or protrude from an outer surface of, the sensor 301a, thereby providing increased ability for various sensor components to dissipate excess heat. By being on the outer surface of the sensor 301a in certain embodiments, the heat sink 350a can be exposed to the air and thereby facilitate more efficient cooling. In an embodiment, one or more of the emitters (see FIG. 1) generate sufficient heat that inclusion of the heat sink 350a can advantageously allow the sensor 301a to remain safely cooled. The heat sink 350a can include one or more materials that help dissipate heat, such as, for example, aluminum, steel, copper, carbon, combinations of the same, or the like. For example, in some embodiments, the emitter shell 304a can include a heat conducting material that is also readily and relatively inexpensively moldable into desired shapes and forms.

[0121] In some embodiments, the heat sink 350a includes metallicized plastic. The metallicized plastic can include aluminum and carbon, for example. The material can allow for improved thermal conductivity and diffusivity, which can increase commercial viability of the heat sink. In some embodiments, the material selected to construct the heat sink 350a can include a thermally conductive liquid crystalline polymer, such as CoolPoly® D5506, commercially available from Cool Polymers®, Inc. of Warwick, R.I. Such a material can be selected for its electrically non-conductive and dielectric properties so as, for example, to aid in electrical shielding. In an embodiment, the heat sink 350a provides improved heat transfer properties when the sensor 301a is active for short intervals of less than a full day's use. In an embodiment, the heat sink 350a can advantageously provide improved heat transfers in about three (3) to about four (4) minute intervals, for example, although a heat sink 350a can be selected that performs effectively in shorter or longer intervals.

[0122] Moreover, the heat sink 350a can have different shapes and configurations for aesthetic as well as for functional purposes. In an embodiment, the heat sink is configured to maximize heat dissipation, for example, by maximizing surface area. In an embodiment, the heat sink 350a is molded into a generally curved surface and includes one or more fins, undulations, grooves, or channels. The example heat sink 350a shown includes fins 351a (see FIG. 3A).

[0123] An alternative shape of a sensor 301b and heat sink 350b is shown in FIG. 3D. The sensor 301b can include some or all of the features of the sensor 301a. For example, the sensor 301b includes an enclosure 302b formed by an emitter shell 304b and a detector shell 306b, pivotably connected about a pivot 303a. The emitter shell 304b can also include absorbing opaque material on one or more flaps 307b, and the detector shell 306a can also include absorbing opaque material at various areas, such as lower area 308b.

[0124] However, the shape of the sensor 301b is different in this embodiment. In particular, the heat sink 350b includes comb protrusions 351b. The comb protrusions 351b are exposed to the air in a similar manner to the fins 351a of the heat sink 350a, thereby facilitating efficient cooling of the sensor 301b.

[0125] FIG. 3E illustrates a more detailed example of a detector shell 306b of the sensor 301b. The features described with respect to the detector shell 306b can also be used with the detector shell 306a of the sensor 301a.

[0126] As shown, the detector shell 306b includes detectors 316. The detectors 316 can have a predetermined spacing 340 from each other, or a spatial relationship among one another that results in a spatial configuration. This spatial configura-

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tion can purposefully create a variation of path lengths among detectors 316 and the emitter discussed above.

[0127] In the depicted embodiment, the detector shell 316 can hold multiple (e.g., two, three, four, etc.) photodiode arrays that are arranged in a two-dimensional grid pattern. Multiple photodiode arrays can also be useful to detect light piping (e.g., light that bypasses measurement site 102). In the detector shell 316, walls can be provided to separate the individual photodiode arrays to prevent or reduce mixing of light signals from distinct quadrants. In addition, the detector shell 316 can be covered by windows of transparent material, such as glass, plastic, or the like, to allow maximum or increased transmission of power light captured. In various embodiments, the transparent materials used can also be partially transparent or translucent or can otherwise pass some or all of the optical radiation passing through them. As noted, this window can include some shielding in the form of an embedded grid of wiring, or a conductive layer or coating.

[0128] As further illustrated by FIG. 3E, the detectors 316 can have a spatial configuration of a grid. However, the detectors 316 can be arranged in other configurations that vary the path length. For example, the detectors 316 can be arranged in a linear array, a logarithmic array, a two-dimensional array, a zig-zag pattern, or the like. Furthermore, any number of the detectors 316 can be employed in certain embodiments.

[0129] FIG. 3F illustrates another embodiment of a sensor 301f. The sensor 301f can include some or all of the features of the sensor 301a of FIG. 3A described above. For example, the sensor 301f includes an enclosure 302f formed by an upper section or emitter shell 304f, which is pivotably connected with a lower section or detector shell 306f around a pivot point 303f. The emitter shell 304f can also include absorbing opaque material on various areas, such as on one or more flaps 307f, to reduce ambient light entering the sensor 301f. The detector shell 306f can also include absorbing opaque material at various areas, such as a lower area 308f. The sensor 301f also includes a heat sink 350f, which includes fins 351f.

[0130] In addition to these features, the sensor 301f includes a flex circuit cover 360, which can be made of plastic or another suitable material. The flex circuit cover 360 can cover and thereby protect a flex circuit (not shown) that extends from the emitter shell 304f to the detector shell 306f. An example of such a flex circuit is illustrated in U.S. Publication No. 2006/0211924, incorporated above (see FIG. 46 and associated description, which is hereby specifically incorporated by reference). The flex circuit cover 360 is shown in more detail below in FIG. 17.

[0131] In addition, sensors 301a-f has extra length—extends to second joint on finger—Easier to place, harder to move due to cable, better for light piping

[0132] FIGS. 4A through 4C illustrate example arrangements of a protrusion 405, which is an embodiment of the protrusion 305 described above. In an embodiment, the protrusion 405 can include a measurement site contact area 470. The measurement site contact area 470 can include a surface that molds body tissue of a measurement site, such as a finger, into a flat or relatively flat surface.

[0133] The protrusion 405 can have dimensions that are suitable for a measurement site such as a patient's finger. As shown, the protrusion 405 can have a length 400, a width 410, and a height 430. The length 400 can be from about 9 to about 11 millimeters, e.g., about 10 millimeters. The width 410 can be from about 7 to about 9 millimeters, e.g., about 8 millime-

ters. The height 430 can be from about 0.5 millimeters to about 3 millimeters, e.g., about 2 millimeters. In an embodiment, the dimensions 400, 410, and 430 can be selected such that the measurement site contact area 470 includes an area of about 80 square millimeters, although larger and smaller areas can be used for different sized tissue for an adult, an adolescent, or infant, or for other considerations.

[0134] The measurement site contact area 470 can also include differently shaped surfaces that conform the measurement site into different shapes. For example, the measurement site contact area 470 can be generally curved and/or convex with respect to the measurement site. The measurement site contact area 470 can be other shapes that reduce or even minimize air between the protrusion 405 and or the measurement site. Additionally, the surface pattern of the measurement site contact area 470 can vary from smooth to bumpy, e.g., to provide varying levels of grip.

[0135] In FIGS. 4A and 4C, openings or windows 420, 421, 422, and 423 can include a wide variety of shapes and sizes, including for example, generally square, circular, triangular, or combinations thereof. The windows 420, 421, 422, and 423 can be of non-uniform shapes and sizes. As shown, the windows 420, 421, 422, and 423 can be evenly spaced out in a grid like arrangement. Other arrangements or patterns of arranging the windows 420, 421, 422, and 423 are possible. For example, the windows 420, 421, 422, and 423 can be placed in a triangular, circular, or linear arrangement. In some embodiments, the windows 420, 421, 422, and 423 can be placed at different heights with respect to the finger bed 310 of FIG. 3. The windows 420, 421, 422, and 423 can also mimic or approximately mimic a configuration of, or even house, a plurality of detectors.

[0136] FIGS. 6A through 6D illustrate another embodiment of a protrusion 605 that can be used as the tissue shaper 105 described above or in place of the protrusions 305, 405 described above. The depicted protrusion 605 is a partially cylindrical lens having a partial cylinder 608 and an extension 610. The partial cylinder 608 can be a half cylinder in some embodiments; however, a smaller or greater portion than half of a cylinder can be used. Advantageously, in certain embodiments, the partially cylindrical protrusion 605 focuses light onto a smaller area, such that fewer detectors can be used to detect the light attenuated by a measurement site.

[0137] FIG. 6A illustrates a perspective view of the partially cylindrical protrusion 605. FIG. 6B illustrates a front elevation view of the partially cylindrical protrusion 605. FIG. 6C illustrates a side view of the partially cylindrical protrusion 605. FIG. 6D illustrates a top view of the partially cylindrical protrusion 605.

[0138] Advantageously, in certain embodiments, placing the partially cylindrical protrusion 605 over the photodiodes in any of the sensors described above adds multiple benefits to any of the sensors described above. In one embodiment, the partially cylindrical protrusion 605 penetrates into the tissue and reduces the path length of the light traveling in the tissue, similar to the protrusions described above.

[0139] The partially cylindrical protrusion 605 can also collect light from a large surface and focus down the light to a smaller area. As a result, in certain embodiments, signal strength per area of the photodiode can be increased. The partially cylindrical protrusion 605 can therefore facilitate a lower cost sensor because, in certain embodiments, less photodiode area can be used to obtain the same signal strength. Less photodiode area can be realized by using smaller pho-



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photodiodes or fewer photodiodes (see, e.g., FIG. 14). If fewer or smaller photodiodes are used, the partially cylindrical protrusion 605 can also facilitate an improved SNR of the sensor because fewer or smaller photodiodes can have less dark current.

[0140] The dimensions of the partially cylindrical protrusion 605 can vary based on, for instance, a number of photodiodes used with the sensor. Referring to FIG. 6C, the overall height of the partially cylindrical protrusion 605 (measurement “a”) in some implementations is about 1 to about 3 mm. A height in this range can allow the partially cylindrical protrusion 605 to penetrate into the pad of the finger or other tissue and reduce the distance that light travels through the tissue. Other heights, however, of the partially cylindrical protrusion 605 can also accomplish this objective. For example, the chosen height of the partially cylindrical protrusion 605 can be selected based on the size of the measurement site, whether the patient is an adult or child, and so on. In an embodiment, the height of the protrusion 605 is chosen to provide as much tissue thickness reduction as possible while reducing or preventing occlusion of blood vessels in the tissue.

[0141] Referring to FIG. 6D, the width of the partially cylindrical protrusion 605 (measurement “b”) can be about 3 to about 5 mm. In one embodiment, the width is about 4 mm. In one embodiment, a width in this range provides good penetration of the partially cylindrical protrusion 605 into the tissue to reduce the path length of the light. Other widths, however, of the partially cylindrical protrusion 605 can also accomplish this objective. For example, the width of the partially cylindrical protrusion 605 can vary based on the size of the measurement site, whether the patient is an adult or child, and so on. In addition, the length of the protrusion 605 could be about 10 mm, or about 8 mm to about 12 mm, or smaller than 8 mm or greater than 12 mm.

[0142] In certain embodiments, the focal length ( $f$ ) for the partially cylindrical protrusion 605 can be expressed as:

$$f = \frac{R}{n-1},$$

where  $R$  is the radius of curvature of the partial cylinder 608 and  $n$  is the index of refraction of the material used. In certain embodiments, the radius of curvature can be between about 1.5 mm and about 2 mm. In another embodiment, the partially cylindrical protrusion 605 can include a material, such as nBK7 glass, with an index of refraction of around 1.5 at 1300 nm, which can provide focal lengths of between about 3 mm and about 4 mm.

[0143] A partially cylindrical protrusion 605 having a material with a higher index of refraction such as nSF11 glass (e.g.,  $n=1.75$  at 1300 nm) can provide a shorter focal length and possibly a smaller photodiode chip, but can also cause higher reflections due to the index of refraction mismatch with air. Many types of glass or plastic can be used with index of refraction values ranging from, for example, about 1.4 to about 1.9. The index of refraction of the material of the protrusion 605 can be chosen to improve or optimize the light focusing properties of the protrusion 605. A plastic partially cylindrical protrusion 605 could provide the cheapest option in high volumes but can also have some undesired light absorption peaks at wavelengths higher than 1500 nm. Other

focal lengths and materials having different indices of refraction can be used for the partially cylindrical protrusion 605.

[0144] Placing a photodiode at a given distance below the partially cylindrical protrusion 605 can facilitate capturing some or all of the light traveling perpendicular to the lens within the active area of the photodiode (see FIG. 14). Different sizes of the partially cylindrical protrusion 605 can use different sizes of photodiodes. The extension 610 added onto the bottom of the partial cylinder 608 is used in certain embodiments to increase the height of the partially cylindrical protrusion 605. In an embodiment, the added height is such that the photodiodes are at or are approximately at the focal length of the partially cylindrical protrusion 605. In an embodiment, the added height provides for greater thinning of the measurement site. In an embodiment, the added height assists in deflecting light piped through the sensor. This is because light piped around the sensor passes through the side walls of the added height without being directed toward the detectors. The extension 610 can also further facilitate the protrusion 605 increasing or maximizing the amount of light that is provided to the detectors. In some embodiments, the extension 610 can be omitted.

[0145] FIG. 6E illustrates another view of the sensor 301f of FIG. 3F, which includes an embodiment of a partially cylindrical protrusion 605b. Like the sensor 301A shown in FIGS. 3B and 3C, the sensor 301f includes a finger bed 310f. The finger bed 310f includes a generally curved surface shaped generally to receive tissue, such as a human digit. The finger bed 310f also includes the ridges or channels 314 described above with respect to FIGS. 3B and 3C.

[0146] The example of finger bed 310f shown also includes the protrusion 605b, which includes the features of the protrusion 605 described above. In addition, the protrusion 605b also includes chamfered edges 607 on each end to provide a more comfortable surface for a finger to slide across (see also FIG. 14D). In another embodiment, the protrusion 605b could instead include a single chamfered edge 607 proximal to the ridges 314. In another embodiment, one or both of the chamfered edges 607 could be rounded.

[0147] The protrusion 605b also includes a measurement site contact area 670 that can contact body tissue of a measurement site. The protrusion 605b can be removed from or integrated with the finger bed 310f. Interchangeable, differently shaped protrusions 605b can also be provided, which can correspond to different finger shapes, characteristics, opacity, sizes, or the like.

[0148] FIGS. 7A and 7B illustrate block diagrams of sensors 701 that include example arrangements of conductive glass or conductive coated glass for shielding. Advantageously, in certain embodiments, the shielding can provide increased SNR. The features of the sensors 701 can be implemented with any of the sensors 101, 201, 301 described above. Although not shown, the partially cylindrical protrusion 605 of FIG. 6 can also be used with the sensors 701 in certain embodiments.

[0149] For example, referring specifically to FIG. 7A, the sensor 701a includes an emitter housing 704a and a detector housing 706. The emitter housing 704a includes LEDs 104. The detector housing 706a includes a tissue bed 710a with an opening or window 703a, the conductive glass 730a, and one or more photodiodes for detectors 106 provided on a submount 707a.

[0150] During operation, a finger 102 can be placed on the tissue bed 710a and optical radiation can be emitted from the

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LEDs 104. Light can then be attenuated as it passes through or is reflected from the tissue of the finger 102. The attenuated light can then pass through the opening 703a in the tissue bed 710a. Based on the received light, the detectors 106 can provide a detector signal 107, for example, to the front end interface 108 (see FIG. 1).

[0151] In the depicted embodiment, the conductive glass 730 is provided in the opening 703. The conductive glass 730 can thus not only permit light from the finger to pass to the detectors 106, but it can also supplement the shielding of the detectors 106 from noise. The conductive glass 730 can include a stack or set of layers. In FIG. 7A, the conductive glass 730a is shown having a glass layer 731 proximate the finger 102 and a conductive layer 733 electrically coupled to the shielding 790a.

[0152] In an embodiment, the conductive glass 730a can be coated with a conductive, transparent or partially transparent material, such as a thin film of indium tin oxide (ITO). To supplement electrical shielding effects of a shielding enclosure 790a, the conductive glass 730a can be electrically coupled to the shielding enclosure 790a. The conductive glass 730a can be electrically coupled to the shielding 704a based on direct contact or via other connection devices, such as a wire or another component.

[0153] The shielding enclosure 790a can be provided to encompass the detectors 106 to reduce or prevent noise. For example, the shielding enclosure 790a can be constructed from a conductive material, such as copper, in the form of a metal cage. The shielding or enclosure a can include an opaque material to not only reduce electrical noise, but also ambient optical noise.

[0154] In some embodiments, the shielding enclosure 790a can be constructed in a single manufactured component with or without the use of conductive glass. This form of construction may be useful in order to reduce costs of manufacture as well as assist in quality control of the components. Furthermore, the shielding enclosure 790a can also be used to house various other components, such as sigma delta components for various embodiments of front end interfaces 108.

[0155] Referring to FIG. 7B, another block diagram of an example sensor 701b is shown. A tissue bed 710b of the sensor 701b includes a protrusion 705b, which is in the form of a convex bump. The protrusion 705b can include all of the features of the protrusions or tissue shaping materials described above. For example, the protrusion 705b includes a contact area 370 that comes in contact with the finger 102 and which can include one or more openings 703b. One or more components of conductive glass 730b can be provided in the openings 703. For example, in an embodiment, each of the openings 703 can include a separate window of the conductive glass 730b. In an embodiment, a single piece of the conductive glass 730b can be used for some or all of the openings 703b. The conductive glass 730b is smaller than the conductive glass 730a in this particular embodiment.

[0156] A shielding enclosure 790b is also provided, which can have all the features of the shielding enclosure 790a. The shielding enclosure 790b is smaller than the shielding enclosure 790a; however, a variety of sizes can be selected for the shielding enclosures 790.

[0157] In some embodiments, the shielding enclosure 790b can be constructed in a single manufactured component with or without the use of conductive glass. This form of construction may be useful in order to reduce costs of manufacture as well as assist in quality control of the components. Further-

more, the shielding enclosure 790b can also be used to house various other components, such as sigma delta components for various embodiments of front end interfaces 108.

[0158] FIGS. 8A through 8D illustrate a perspective view, side views, and a bottom elevation view of the conductive glass described above with respect to the sensors 701a, 701b. As shown in the perspective view of FIG. 8A and side view of FIG. 8B, the conductive glass 730 includes the electrically conductive material 733 described above as a coating on the glass layer 731 described above to form a stack. In an embodiment where the electrically conductive material 733 includes indium tin oxide, surface resistivity of the electrically conductive material 733 can range approximately from 30 ohms per square inch to 500 ohms per square inch, or approximately 30, 200, or 500 ohms per square inch. As would be understood by a person of skill in the art from the present disclosure, other resistivities can also be used which are less than 30 ohms or more than 500 ohms. Other transparent, electrically conductive materials can be used as the material 733.

[0159] Although the conductive material 733 is shown spread over the surface of the glass layer 731, the conductive material 733 can be patterned or provided on selected portions of the glass layer 731. Furthermore, the conductive material 733 can have uniform or varying thickness depending on a desired transmission of light, a desired shielding effect, and other considerations.

[0160] In FIG. 8C, a side view of a conductive glass 830a is shown to illustrate an embodiment where the electrically conductive material 733 is provided as an internal layer between two glass layers 731, 835. Various combinations of integrating electrically conductive material 733 with glass are possible. For example, the electrically conductive material 733 can be a layer within a stack of layers. This stack of layers can include one or more layers of glass 731, 835, as well as one or more layers of conductive material 733. The stack can include other layers of materials to achieve desired characteristics.

[0161] In FIG. 8D, a bottom perspective view is shown to illustrate an embodiment where a conductive glass 830b can include conductive material 837 that occupies or covers a portion of a glass layer 839. This embodiment can be useful, for example, to create individual, shielded windows for detectors 106, such as those shown in FIG. 3C. The conductive material 837 can be patterned to include an area 838 to allow light to pass to detectors 106 and one or more strips 841 to couple to the shielding 704 of FIG. 7.

[0162] Other configurations and patterns for the conductive material can be used in certain embodiments, such as, for example, a conductive coating lining periphery edges, a conductive coating outlaid in a pattern including a grid or other pattern, a speckled conductive coating, coating outlaid in lines in either direction or diagonally, varied thicknesses from the center out or from the periphery in, or other suitable patterns or coatings that balance the shielding properties with transparency considerations.

[0163] FIG. 9 depicts an example graph 900 that illustrates comparative results obtained by an example sensor having components similar to those disclosed above with respect to FIGS. 7 and 8. The graph 900 depicts the results of the percentage of transmission of varying wavelengths of light for different types of windows used in the sensors described above.

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[0164] A line 915 on the graph 900 illustrates example light transmission of a window made from plain glass. As shown, the light transmission percentage of varying wavelengths of light is approximately 90% for a window made from plain glass. A line 920 on the graph 900 demonstrates an example light transmission percentage for an embodiment in which a window is made from glass having an ITO coating with a surface resistivity of 500 ohms per square inch. A line 925 on the graph 900 shows an example light transmission for an embodiment in which a window is made from glass that includes a coating of ITO oxide with a surface resistivity of 200 ohms per square inch. A line 930 on the graph 900 shows an example light transmission for an embodiment in which a window is made from glass that includes a coating of ITO oxide with a surface resistivity of 30 ohms per square inch.

[0165] The light transmission percentage for a window with currently available embedded wiring can have a light transmission percentage of approximately 70%. This lower percentage of light transmission can be due to the opacity of the wiring employed in a currently available window with wiring. Accordingly, certain embodiments of glass coatings described herein can employ, for example, ITO coatings with different surface resistivity depending on the desired light transmission, wavelengths of light used for measurement, desired shielding effect, and other criteria.

[0166] FIGS. 10A through 10B illustrate comparative noise floors of example implementations of the sensors described above. Noise can include optical noise from ambient light and electromagnetic noise, for example, from surrounding electrical equipment. In FIG. 10A, a graph 1000 depicts possible noise floors for different frequencies of noise for an embodiment in which one of the sensors described above included separate windows for four (4) detectors 106. One or more of the windows included an embedded grid of wiring as a noise shield. Symbols 1030-1033 illustrate the noise floor performance for this embodiment. As can be seen, the noise floor performance can vary for each of the openings and based on the frequency of the noise.

[0167] In FIG. 10B, a graph 1050 depicts a noise floor for frequencies of noise 1070 for an embodiment in which the sensor included separate openings for four (4) detectors 106 and one or more windows that include an ITO coating. In this embodiment, a surface resistivity of the ITO used was about 500 ohms per square inch. Symbols 1080-1083 illustrate the noise floor performance for this embodiment. As can be seen, the noise floor performance for this embodiment can vary less for each of the openings and provide lower noise floors in comparison to the embodiment of FIG. 10A.

[0168] FIG. 11A illustrates an example structure for configuring the set of optical sources of the emitters described above. As shown, an emitter 104 can include a driver 1105, a thermistor 1120, a set of top-emitting LEDs 1102 for emitting red and/or infrared light, a set of side-emitting LEDs 1104 for emitting near infrared light, and a submount 1106.

[0169] The thermistor 1120 can be provided to compensate for temperature variations. For example, the thermistor 1120 can be provided to allow for wavelength centroid and power drift of LEDs 1102 and 1104 due to heating. In addition, other thermistors (not shown) can be employed, for example, to measure a temperature of a measurement site. The temperature can be displayed on a display device and used by a caregiver. Such a temperature can also be helpful in correcting for wavelength drift due to changes in water absorption, which can be temperature dependent, thereby providing more

accurate data useful in detecting blood analytes like glucose. In addition, using a thermistor or other type of temperature sensitive device may be useful for detecting extreme temperatures at the measurement site that are too hot or too cold. The presence of low perfusion may also be detected, for example, when the finger of a patient has become too cold. Moreover, shifts in temperature at the measurement site can alter the absorption spectrum of water and other tissue in the measurement site. A thermistor's temperature reading can be used to adjust for the variations in absorption spectrum changes in the measurement site.

[0170] The driver 1105 can provide pulses of current to the emitter 1104. In an embodiment, the driver 1105 drives the emitter 1104 in a progressive fashion, for example, in an alternating manner based on a control signal from, for example, a processor (e.g., the processor 110). For example, the driver 1105 can drive the emitter 1104 with a series of pulses to about 1 milliwatt (mW) for visible light to light at about 1300 nm and from about 40 mW to about 100 mW for light at about 1600 nm to about 1700 nm. However, a wide number of driving powers and driving methodologies can be used. The driver 1105 can be synchronized with other parts of the sensor and can minimize or reduce any jitter in the timing of pulses of optical radiation emitted from the emitter 1104. In some embodiments, the driver 1105 is capable of driving the emitter 1104 to emit an optical radiation in a pattern that varies by less than about 10 parts-per-million; however other amounts of variation can be used.

[0171] The submount 1106 provides a support structure in certain embodiments for aligning the top-emitting LEDs 1102 and the side-emitting LEDs 1104 so that their optical radiation is transmitted generally towards the measurement site. In some embodiments, the submount 1106 is also constructed of aluminum nitride (AlN) or beryllium oxide (BeO) for heat dissipation, although other materials or combinations of materials suitable for the submount 1106 can be used.

[0172] FIG. 11B illustrates a configuration of emitting optical radiation into a measurement site for measuring a blood constituent or analyte like glucose. In some embodiments, emitter 104 may be driven in a progressive fashion to minimize noise and increase SNR of sensor 101. For example, emitter 104 may be driven based on a progression of power/current delivered to LEDs 1102 and 1104.

[0173] In some embodiments, emitter 104 may be configured to emit pulses centered about 905 nm, about 1050 nm, about 1200 nm, about 1300 nm, about 1330 nm, about 1610 nm, about 1640 nm, and about 1665 nm. In another embodiment, the emitter 104 may emit optical radiation ranging from about 860 nm to about 950 nm, about 950 nm to about 1100 nm, about 1100 nm to about 1270 nm, about 1250 nm to about 1350 nm, about 1300 nm to about 1360 nm, and about 1590 nm to about 1700 nm. Of course, emitter 104 may be configured to transmit any of a variety of wavelengths of visible, or near-infrared optical radiation.

[0174] For purposes of illustration, FIG. 11B shows a sequence of pulses of light at wavelengths of around 905 nm, around 1200 nm, around 1300 nm, and around 1330 nm from top emitting LEDs 1102. FIG. 11B also shows that emitter 104 may then emit pulses centered at around 1630 nm, around 1660 nm, and around 1615 nm from side emitting LEDs 1104. Emitter 104 may be progressively driven at higher power/current. This progression may allow driver circuit 105 to stabilize in its operations, and thus, provide a more stable current/power to LEDs 1102 and 1104.

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[0175] For example, as shown in FIG. 11B, the sequence of optical radiation pulses are shown having a logarithmic-like progression in power/current. In some embodiments, the timing of these pulses is based on a cycle of about 400 slots running at 48 kHz (e.g. each time slot may be approximately 0.02 ms or 20 microseconds). An artisan will recognize that term “slots” includes its ordinary meaning, which includes a time period that may also be expressed in terms of a frequency. In the example shown, pulses from top emitting LEDs 1102 may have a pulse width of about 40 time slots (e.g., about 0.8 ms) and an off period of about 4 time slots in between. In addition, pulses from side emitting LEDs 1104 (e.g., or a laser diode) may have a pulse width of about 60 time slots (e.g., about 1.25 ms) and a similar off period of about 4 time slots. A pause of about 70 time slots (e.g. 1.5 ms) may also be provided in order to allow driver circuit 1105 to stabilize after operating at higher current/power.

[0176] As shown in FIG. 11B, top emitting LEDs 1102 may be initially driven with a power to approximately 1 mW at a current of about 20-100 mA. Power in these LEDs may also be modulated by using a filter or covering of black dye to reduce power output of LEDs. In this example, top emitting LEDs 1102 may be driven at approximately 0.02 to 0.08 mW. The sequence of the wavelengths may be based on the current requirements of top emitting LEDs 502 for that particular wavelength. Of course, in other embodiments, different wavelengths and sequences of wavelengths may be output from emitter 104.

[0177] Subsequently, side emitting LEDs 1104 may be driven at higher powers, such as about 40-100 mW and higher currents of about 600-800 mA. This higher power may be employed in order to compensate for the higher opacity of tissue and water in measurement site 102 to these wavelengths. For example, as shown, pulses at about 1630 nm, about 1660 nm, and about 1615 nm may be output with progressively higher power, such as at about 40 mW, about 50 mW, and about 60 mW, respectively. In this embodiment, the order of wavelengths may be based on the optical characteristics of that wavelength in tissue as well as the current needed to drive side emitting LEDs 1104. For example, in this embodiment, the optical pulse at about 1615 nm is driven at the highest power due to its sensitivity in detecting analytes like glucose and the ability of light at this wavelength to penetrate tissue. Of course, different wavelengths and sequences of wavelengths may be output from emitter 104.

[0178] As noted, this progression may be useful in some embodiments because it allows the circuitry of driver circuit 1105 to stabilize its power delivery to LEDs 1102 and 1104. Driver circuit 1105 may be allowed to stabilize based on the duty cycle of the pulses or, for example, by configuring a variable waiting period to allow for stabilization of driver circuit 1105. Of course, other variations in power/current and wavelength may also be employed in the present disclosure.

[0179] Modulation in the duty cycle of the individual pulses may also be useful because duty cycle can affect the signal noise ratio of the system 100. That is, as the duty cycle is increased so may the signal to noise ratio.

[0180] Furthermore, as noted above, driver circuit 1105 may monitor temperatures of the LEDs 1102 and 1104 using the thermistor 1120 and adjust the output of LEDs 1102 and 1104 accordingly. Such a temperature may be to help sensor 101 correct for wavelength drift due to changes in water absorption, which can be temperature dependent.

[0181] FIG. 11C illustrates another exemplary emitter that may be employed in the sensor according to an embodiment of the disclosure. As shown, the emitter 104 can include components mounted on a substrate 1108 and on submount 1106. In particular, top-emitting LEDs 1102 for emitting red and/or infrared light may be mounted on substrate 1108. Side emitting LEDs 1104 may be mounted on submount 1106. As noted, side-emitting LEDs 1104 may be included in emitter 104 for emitting near infrared light.

[0182] As also shown, the sensor of FIG. 11C may include a thermistor 1120. As noted, the thermistor 1120 can be provided to compensate for temperature variations. The thermistor 1120 can be provided to allow for wavelength centroid and power drift of LEDs 1102 and 1104 due to heating. In addition, other thermistors (not shown) can be employed, for example, to measure a temperature of a measurement site. Such a temperature can be helpful in correcting for wavelength drift due to changes in water absorption, which can be temperature dependent, thereby providing more accurate data useful in detecting blood analytes like glucose.

[0183] In some embodiments, the emitter 104 may be implemented without the use of side emitting LEDs. For example, certain blood constituents, such as total hemoglobin, can be measured by embodiments of the disclosure without the use of side emitting LEDs. FIG. 11D illustrates another exemplary emitter that may be employed in the sensor according to an embodiment of the disclosure. In particular, an emitter 104 that is configured for a blood constituent, such as total hemoglobin, is shown. The emitter 104 can include components mounted on a substrate 1108. In particular, top-emitting LEDs 1102 for emitting red and/or infrared light may be mounted on substrate 1108.

[0184] As also shown, the emitter of FIG. 11D may include a thermistor 1120. The thermistor 1120 can be provided to compensate for temperature variations. The thermistor 1120 can be provided to allow for wavelength centroid and power drift of LEDs 1102 due to heating.

[0185] FIG. 12A illustrates a detector submount 1200 having photodiode detectors that are arranged in a grid pattern on the detector submount 1200 to capture light at different quadrants from a measurement site. One detector submount 1200 can be placed under each window of the sensors described above, or multiple windows can be placed over a single detector submount 1200. The detector submount 1200 can also be used with the partially cylindrical protrusion 605 described above with respect to FIG. 6.

[0186] The detectors include photodiode detectors 1-4 that are arranged in a grid pattern on the submount 1200 to capture light at different quadrants from the measurement site. As noted, other patterns of photodiodes, such as a linear row, or logarithmic row, can also be employed in certain embodiments.

[0187] As shown, the detectors 1-4 may have a predetermined spacing from each other, or spatial relationship among one another that result in a spatial configuration. This spatial configuration can be configured to purposefully create a variation of path lengths among detectors 106 and the point light source discussed above.

[0188] Detectors may hold multiple (e.g., two, three, four, etc.) photodiode arrays that are arranged in a two-dimensional grid pattern. Multiple photodiode arrays may also be useful to detect light piping (i.e., light that bypasses measurement site 102). As shown, walls may separate the individual photodiode arrays to prevent mixing of light signals from

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distinct quadrants. In addition, as noted, the detectors may be covered by windows of transparent material, such as glass, plastic, etc., to allow maximum transmission of power light captured. As noted, this window may comprise some shielding in the form of an embedded grid of wiring, or a conductive layer or coating.

[0189] FIGS. 12B through 12D illustrate a simplified view of exemplary arrangements and spatial configurations of photodiodes for detectors 106. As shown, detectors 106 may comprise photodiode detectors 1-4 that are arranged in a grid pattern on detector submount 1200 to capture light at different quadrants from measurement site 102.

[0190] As noted, other patterns of photodiodes may also be employed in embodiments of the present disclosure, including, for example, stacked or other configurations recognizable to an artisan from the disclosure herein. For example, detectors 106 may be arranged in a linear array, a logarithmic array, a two-dimensional array, and the like. Furthermore, an artisan will recognize from the disclosure herein that any number of detectors 106 may be employed by embodiments of the present disclosure.

[0191] For example, as shown in FIG. 12B, detectors 106 may comprise photodiode detectors 1-4 that are arranged in a substantially linear configuration on submount 1200. In this embodiment shown, photodiode detectors 1-4 are substantially equally spaced apart (e.g., where the distance D is substantially the same between detectors 1-4).

[0192] In FIG. 12C, photodiode detectors 1-4 may be arranged in a substantially linear configuration on submount 1200, but may employ a substantially progressive, substantially logarithmic, or substantially semi-logarithmic spacing (e.g., where distances  $D1 > D2 > D3$ ). This arrangement or pattern may be useful for use on a patient's finger and where the thickness of the finger gradually increases.

[0193] In FIG. 12D, a different substantially grid pattern on submount 1200 of photodiode detectors 1-4 is shown. As noted, other patterns of detectors may also be employed in embodiments of the present invention.

[0194] FIGS. 12E through 12H illustrate several embodiments of photodiodes that may be used in detectors 106. As shown in these figures, a photodiode 1202 of detector 106 may comprise a plurality of active areas 1204. These active areas 204 may be coupled together via a common cathode 1206 or anode 1208 in order to provide a larger effective detection area.

[0195] In particular, as shown in FIG. 12E, photodiode 1202 may comprise two (2) active areas 1204a and 1204b. In FIG. 12F, photodiode 1202 may comprise four (4) active areas 1204c-f. In FIG. 12G, photodiode 1202 may comprise three (3) active areas 1204g-i. In FIG. 12H, photodiode 1202 may comprise nine (9) active areas 1204j-r. The use of smaller active areas may be useful because smaller active areas can be easier to fabricate and can be fabricated with higher purity. However, one skilled in the art will recognize that various sizes of active areas may be employed in the photodiode 1202.

[0196] FIG. 13 illustrates an example multi-stream process 1300. The multi-stream process 1300 can be implemented by the data collection system 100 and/or by any of the sensors described above. As shown, a control signal from a signal processor 1310 controls a driver 1305. In response, an emitter 1304 generates a pulse sequence 1303 from its emitter (e.g., its LEDs) into a measurement site or sites 1302. As described above, in some embodiments, the pulse sequence 1303 is

controlled to have a variation of about 10 parts per million or less. Of course, depending on the analyte desired, the tolerated variation in the pulse sequence 1303 can be greater (or smaller).

[0197] In response to the pulse sequence 1300, detectors 1 to n (n being an integer) in a detector 1306 capture optical radiation from the measurement site 1302 and provide respective streams of output signals. Each signal from one of detectors 1-n can be considered a stream having respective time slots corresponding to the optical pulses from emitter sets 1-n in the emitter 1304. Although n emitters and n detectors are shown, the number of emitters and detectors need not be the same in certain implementations.

[0198] A front end interface 1308 can accept these multiple streams from detectors 1-n and deliver one or more signals or composite signal(s) back to the signal processor 1310. A stream from the detectors 1-n can thus include measured light intensities corresponding to the light pulses emitted from the emitter 1304.

[0199] The signal processor 1310 can then perform various calculations to measure the amount of glucose and other analytes based on these multiple streams of signals. In order to help explain how the signal processor 1310 can measure analytes like glucose, a primer on the spectroscopy employed in these embodiments will now be provided.

[0200] Spectroscopy is premised upon the Beer-Lambert law. According to this law, the properties of a material, e.g., glucose present in a measurement site, can be deterministically calculated from the absorption of light traveling through the material. Specifically, there is a logarithmic relation between the transmission of light through a material and the concentration of a substance and also between the transmission and the length of the path traveled by the light. As noted, this relation is known as the Beer-Lambert law.

[0201] The Beer-Lambert law is usually written as:

$$\text{Absorbance } A = m * b * c, \text{ where:}$$

[0202] m is the wavelength-dependent molar absorptivity coefficient (usually expressed in units of  $M^{-1} \text{ cm}^{-1}$ );

[0203] b is the mean path length; and

[0204] c is the analyte concentration (e.g., the desired parameter).

[0205] In spectroscopy, instruments attempt to obtain the analyte concentration (c) by relating absorbance (A) to transmittance (T). Transmittance is a proportional value defined as:

$$T = I/I_o, \text{ where:}$$

[0206] I is the light intensity measured by the instrument from the measurement site; and

[0207]  $I_o$  is the initial light intensity from the emitter.

[0208] Absorbance (A) can be equated to the transmittance (T) by the equation:

$$A = -\log T$$

[0209] Therefore, substituting equations from above:

$$A = -\log(I/I_o)$$

[0210] In view of this relationship, spectroscopy thus relies on a proportional-based calculation of  $-\log(I/I_o)$  and solving for analyte concentration (c).

[0211] Typically, in order to simplify the calculations, spectroscopy will use detectors that are at the same location in order to keep the path length (b) a fixed, known constant. In addition, spectroscopy will employ various mechanisms to

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definitively know the transmission power ( $I_o$ ), such as a photodiode located at the light source. This architecture can be viewed as a single channel or single stream sensor, because the detectors are at a single location.

[0212] However, this scheme can encounter several difficulties in measuring analytes, such as glucose. This can be due to the high overlap of absorption of light by water at the wavelengths relevant to glucose as well as other factors, such as high self-noise of the components.

[0213] Embodiments of the present disclosure can employ a different approach that in part allows for the measurement of analytes like glucose. Some embodiments can employ a bulk, non-pulsatile measurement in order to confirm or validate a pulsatile measurement. In addition, both the non-pulsatile and pulsatile measurements can employ, among other things, the multi-stream operation described above in order to attain sufficient SNR. In particular, a single light source having multiple emitters can be used to transmit light to multiple detectors having a spatial configuration.

[0214] A single light source having multiple emitters can allow for a range of wavelengths of light to be used. For example, visible, infrared, and near infrared wavelengths can be employed. Varying powers of light intensity for different wavelengths can also be employed.

[0215] Secondly, the use of multiple-detectors in a spatial configuration allow for a bulk measurement to confirm or validate that the sensor is positioned correctly. This is because the multiple locations of the spatial configuration can provide, for example, topology information that indicates where the sensor has been positioned. Currently available sensors do not provide such information. For example, if the bulk measurement is within a predetermined range of values, then this can indicate that the sensor is positioned correctly in order to perform pulsatile measurements for analytes like glucose. If the bulk measurement is outside of a certain range or is an unexpected value, then this can indicate that the sensor should be adjusted, or that the pulsatile measurements can be processed differently to compensate, such as using a different calibration curve or adjusting a calibration curve. This feature and others allow the embodiments to achieve noise cancellation and noise reduction, which can be several times greater in magnitude than what is achievable by currently available technology.

[0216] In order to help illustrate aspects of the multi-stream measurement approach, the following example derivation is provided. Transmittance ( $T$ ) can be expressed as:

$$T = e^{-m \cdot b \cdot c}$$

[0217] In terms of light intensity, this equation can also be rewritten as:

$$I/I_o = e^{-m \cdot b \cdot c}$$

[0218] Or, at a detector, the measured light ( $I$ ) can be expressed as:

$$I = I_o \cdot e^{-m \cdot b \cdot c}$$

[0219] As noted, in the present disclosure, multiple detectors (1 to  $n$ ) can be employed, which results in  $I_1 \dots I_n$  streams of measurements. Assuming each of these detectors have their own path lengths,  $b_1 \dots b_n$ , from the light source, the measured light intensities can be expressed as:

$$I_n/I_o = e^{-m \cdot b_n \cdot c}$$

[0220] The measured light intensities at any two different detectors can be referenced to each other. For example:

$$I_1/I_n = (I_o \cdot e^{-m \cdot b_1 \cdot c}) / (I_o \cdot e^{-m \cdot b_n \cdot c})$$

[0221] As can be seen, the terms,  $I_o$ , cancel out and, based on exponent algebra, the equation can be rewritten as:

$$I_1/I_n = e^{-m(b_1 - b_n)c}$$

[0222] From this equation, the analyte concentration ( $c$ ) can now be derived from bulk signals  $I_1 \dots I_n$  and knowing the respective mean path lengths  $b_1$  and  $b_n$ . This scheme also allows for the cancelling out of  $I_o$ , and thus, noise generated by the emitter 1304 can be cancelled out or reduced. In addition, since the scheme employs a mean path length difference, any changes in mean path length and topological variations from patient to patient are easily accounted. Furthermore, this bulk-measurement scheme can be extended across multiple wavelengths. This flexibility and other features allow embodiments of the present disclosure to measure blood analytes like glucose.

[0223] For example, as noted, the non-pulsatile, bulk measurements can be combined with pulsatile measurements to more accurately measure analytes like glucose. In particular, the non-pulsatile, bulk measurement can be used to confirm or validate the amount of glucose, protein, etc. in the pulsatile measurements taken at the tissue at the measurement site(s) 1302. The pulsatile measurements can be used to measure the amount of glucose, hemoglobin, or the like that is present in the blood. Accordingly, these different measurements can be combined to thus determine analytes like blood glucose.

[0224] FIG. 14A illustrates an embodiment of a detector submount 1400a positioned beneath the partially cylindrical protrusion 605 of FIG. 6 (or alternatively, the protrusion 605b). The detector submount 1400a includes two rows 1408a of detectors 1410a. The partially cylindrical protrusion 605 can facilitate reducing the number and/or size of detectors used in a sensor because the protrusion 605 can act as a lens that focuses light onto a smaller area.

[0225] To illustrate, in some sensors that do not include the partially cylindrical protrusion 605, sixteen detectors can be used, including four rows of four detectors each. Multiple rows of detectors can be used to measure certain analytes, such as glucose or total hemoglobin, among others. Multiple rows of detectors can also be used to detect light piping (e.g., light that bypasses the measurement site). However, using more detectors in a sensor can add cost, complexity, and noise to the sensor.

[0226] Applying the partially cylindrical protrusion 605 to such a sensor, however, could reduce the number of detectors or rows of detectors used while still receiving the substantially same amount of light, due to the focusing properties of the protrusion 605 (see FIG. 14B). This is the example situation illustrated in FIG. 14—two rows 1408a of detectors 1410a are used instead of four. Advantageously, in certain embodiments, the resulting sensor can be more cost effective, have less complexity, and have an improved SNR, due to fewer and/or smaller photodiodes.

[0227] In other embodiments, using the partially cylindrical protrusion 605 can allow the number of detector rows to be reduced to one or three rows of four detectors. The number of detectors in each row can also be reduced. Alternatively, the number of rows might not be reduced but the size of the detectors can be reduced. Many other configurations of detector rows and sizes can also be provided.

[0228] FIG. 14B depicts a front elevation view of the partially cylindrical protrusion 605 (or alternatively, the protrusion 605b) that illustrates how light from emitters (not shown) can be focused by the protrusion 605 onto detectors. The

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protrusion 605 is placed above a detector submount 1400b having one or more detectors 1410b disposed thereon. The submount 1400b can include any number of rows of detectors 1410, although one row is shown.

[0229] Light, represented by rays 1420, is emitted from the emitters onto the protrusion 605. These light rays 1420 can be attenuated by body tissue (not shown). When the light rays 1420 enter the protrusion 605, the protrusion 605 acts as a lens to refract the rays into rays 1422. This refraction is caused in certain embodiments by the partially cylindrical shape of the protrusion 605. The refraction causes the rays 1422 to be focused or substantially focused on the one or more detectors 1410b. Since the light is focused on a smaller area, a sensor including the protrusion 605 can include fewer detectors to capture the same amount of light compared with other sensors.

[0230] FIG. 14C illustrates another embodiment of a detector submount 1400c, which can be disposed under the protrusion 605b (or alternatively, the protrusion 605). The detector submount 1400c includes a single row 1408c of detectors 1410c. The detectors are electrically connected to conductors 1412c, which can be gold, silver, copper, or any other suitable conductive material.

[0231] The detector submount 1400c is shown positioned under the protrusion 605b in a detector subassembly 1450 illustrated in FIG. 14D. A top-down view of the detector subassembly 1450 is also shown in FIG. 14E. In the detector subassembly 1450, a cylindrical housing 1430 is disposed on the submount 1400c. The cylindrical housing 1430 includes a transparent cover 1432, upon which the protrusion 605b is disposed. Thus, as shown in FIG. 14D, a gap 1434 exists between the detectors 1410c and the protrusion 605b. The height of this gap 1434 can be chosen to increase or maximize the amount of light that impinges on the detectors 1410c.

[0232] The cylindrical housing 1430 can be made of metal, plastic, or another suitable material. The transparent cover 1432 can be fabricated from glass or plastic, among other materials. The cylindrical housing 1430 can be attached to the submount 1400c at the same time or substantially the same time as the detectors 1410c to reduce manufacturing costs. A shape other than a cylinder can be selected for the housing 1430 in various embodiments.

[0233] In certain embodiments, the cylindrical housing 1430 (and transparent cover 1432) forms an airtight or substantially airtight or hermetic seal with the submount 1400c. As a result, the cylindrical housing 1430 can protect the detectors 1410c and conductors 1412c from fluids and vapors that can cause corrosion. Advantageously, in certain embodiments, the cylindrical housing 1430 can protect the detectors 1410c and conductors 1412c more effectively than currently-available resin epoxies, which are sometimes applied to solder joints between conductors and detectors.

[0234] In embodiments where the cylindrical housing 1430 is at least partially made of metal, the cylindrical housing 1430 can provide noise shielding for the detectors 1410c. For example, the cylindrical housing 1430 can be soldered to a ground connection or ground plane on the submount 1400c, which allows the cylindrical housing 1430 to reduce noise. In another embodiment, the transparent cover 1432 can include a conductive material or conductive layer, such as conductive glass or plastic. The transparent cover 1432 can include any of the features of the noise shields 790 described above.

[0235] The protrusion 605b includes the chamfered edges 607 described above with respect to FIG. 6E. These cham-

fered edges 607 can allow a patient to more comfortably slide a finger over the protrusion 605b when inserting the finger into the sensor 301f.

[0236] FIG. 14F illustrates a portion of the detector shell 306f, which includes the detectors 1410c on the substrate 1400c. The substrate 1400c is enclosed by a shielding enclosure 1490, which can include the features of the shielding enclosures 790a, 790b described above (see also FIG. 17). The shielding enclosure 1490 can be made of metal. The shielding enclosure 1490 includes a window 1492a above the detectors 1410c, which allows light to be transmitted onto the detectors 1410c.

[0237] A noise shield 1403 is disposed above the shielding enclosure 1490. The noise shield 1403, in the depicted embodiment, includes a window 1492a corresponding to the window 1492a. Each of the windows 1492a, 1492b can include glass, plastic, or can be an opening without glass or plastic. In some embodiments, the windows 1492a, 1492b may be selected to have different sizes or shapes from each other.

[0238] The noise shield 1403 can include any of the features of the conductive glass described above. In the depicted embodiment, the noise shield 1403 extends about three-quarters of the length of the detector shell 306f. In other embodiments, the noise shield 1403 could be smaller or larger. The noise shield 1403 could, for instance, merely cover the detectors 1410c, the submount 1400c, or a portion thereof. The noise shield 1403 also includes a stop 1413 for positioning a measurement site within the sensor 301f. Advantageously, in certain embodiments, the noise shield 1403 can reduce noise caused by light piping.

[0239] A thermistor 1470 is also shown. The thermistor 1470 is attached to the submount 1400c and protrudes above the noise shield 1403. As described above, the thermistor 1470 can be employed to measure a temperature of a measurement site. Such a temperature can be helpful in correcting for wavelength drift due to changes in water absorption, which can be temperature dependent, thereby providing more accurate data useful in detecting blood analytes like glucose.

[0240] In the depicted embodiment, the detectors 1410c are not enclosed in the cylindrical housing 1430. In an alternative embodiment, the cylindrical housing 1430 encloses the detectors 1410c and is disposed under the noise shield 1403. In another embodiment, the cylindrical housing 1430 encloses the detectors 1410c and the noise shield 1403 is not used. If both the cylindrical housing 1403 and the noise shield 1403 are used, either or both can have noise shielding features.

[0241] FIG. 14G illustrates the detector shell 306f of FIG. 14F, with the finger bed 310f disposed thereon. FIG. 14H illustrates the detector shell 306f of FIG. 14G, with the protrusion 605b disposed in the finger bed 310f.

[0242] FIG. 14I illustrates a cutaway view of the sensor 301f. Not all features of the sensor 301f are shown, such as the protrusion 605b. Features shown include the emitter and detector shells 304f, 306f; the flaps 307f; the heat sink 350f and fins 351f; the finger bed 310f; and the noise shield 1403.

[0243] In addition to these features, emitters 1404 are depicted in the emitter shell 304f. The emitters 1404 are disposed on a submount 1401, which is connected to a circuit board 1419. The emitters 1404 are also enclosed within a cylindrical housing 1480. The cylindrical housing 1480 can include all of the features of the cylindrical housing 1430 described above. For example, the cylindrical housing 1480 can be made of metal, can be connected to a ground plane of

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the submount 1401 to provide noise shielding, and can include a transparent cover 1482.

[0244] The cylindrical housing 1480 can also protect the emitters 1404 from fluids and vapors that can cause corrosion. Moreover, the cylindrical housing 1480 can provide a gap between the emitters 1404 and the measurement site (not shown), which can allow light from the emitters 1404 to even out or average out before reaching the measurement site.

[0245] The heat sink 350f, in addition to including the fins 351f, includes a protuberance 352f that extends down from the fins 351f and contacts the submount 1401. The protuberance 352f can be connected to the submount 1401, for example, with thermal paste or the like. The protuberance 352f can sink heat from the emitters 1404 and dissipate the heat via the fins 351f.

[0246] FIGS. 15A and 15B illustrate embodiments of sensor portions 1500A, 1500B that include alternative heat sink features to those described above. These features can be incorporated into any of the sensors described above. For example, any of the sensors above can be modified to use the heat sink features described below instead of or in addition to the heat sink features of the sensors described above.

[0247] The sensor portions 1500A, 1500B shown include LED emitters 1504; however, for ease of illustration, the detectors have been omitted. The sensor portions 1500A, 1500B shown can be included, for example, in any of the emitter shells described above.

[0248] The LEDs 1504 of the sensor portions 1500A, 1500B are connected to a substrate or submount 1502. The submount 1502 can be used in place of any of the submounts described above. The submount 1502 can be a non-electrically conducting material made of any of a variety of materials, such as ceramic, glass, or the like. A cable 1512 is attached to the submount 1502 and includes electrical wiring 1514, such as twisted wires and the like, for communicating with the LEDs 1504. The cable 1512 can correspond to the cables 212 described above.

[0249] Although not shown, the cable 1512 can also include electrical connections to a detector. Only a portion of the cable 1512 is shown for clarity. The depicted embodiment of the cable 1512 includes an outer jacket 1510 and a conductive shield 1506 disposed within the outer jacket 1510. The conductive shield 1506 can be a ground shield or the like that is made of a metal such as braided copper or aluminum. The conductive shield 1506 or a portion of the conductive shield 1506 can be electrically connected to the submount 1502 and can reduce noise in the signal generated by the sensor 1500A, 1500B by reducing RF coupling with the wires 1514. In alternative embodiments, the cable 1512 does not have a conductive shield. For example, the cable 1512 could be a twisted pair cable or the like, with one wire of the twisted pair used as a heat sink.

[0250] Referring specifically to FIG. 15A, in certain embodiments, the conductive shield 1506 can act as a heat sink for the LEDs 1504 by absorbing thermal energy from the LEDs 1504 and/or the submount 1502. An optional heat insulator 1520 in communication with the submount 1502 can also assist with directing heat toward the conductive shield 1506. The heat insulator 1520 can be made of plastic or another suitable material. Advantageously, using the conductive shield 1506 in the cable 1512 as a heat sink can, in certain embodiments, reduce cost for the sensor.

[0251] Referring to FIG. 15B, the conductive shield 1506 can be attached to both the submount 1502 and to a heat sink

layer 1530 sandwiched between the submount 1502 and the optional insulator 1520. Together, the heat sink layer 1530 and the conductive shield 1506 in the cable 1512 can absorb at least part of the thermal energy from the LEDs and/or the submount 1502.

[0252] FIGS. 15C and 15D illustrate implementations of a sensor portion 1500C that includes the heat sink features of the sensor portion 1500A described above with respect to FIG. 15A. The sensor portion 1500C includes the features of the sensor portion 1500A, except that the optional insulator 1520 is not shown. FIG. 15D is a side cutaway view of the sensor portion 1500C that shows the emitters 1504.

[0253] The cable 1512 includes the outer jacket 1510 and the conductive shield 1506. The conductive shield 1506 is soldered to the submount 1502, and the solder joint 1561 is shown. In some embodiments, a larger solder joint 1561 can assist with removing heat more rapidly from the emitters 1504. Various connections 1563 between the submount 1502 and a circuit board 1519 are shown. In addition, a cylindrical housing 1580, corresponding to the cylindrical housing 1480 of FIG. 14I, is shown protruding through the circuit board 1519. The emitters 1504 are enclosed in the cylindrical housing 1580.

[0254] FIGS. 15E and 15F illustrate implementations of a sensor portion 1500E that includes the heat sink features of the sensor portion 1500B described above with respect to FIG. 15B. The sensor portion 1500E includes the heat sink layer 1530. The heat sink layer 1530 can be a metal plate, such as a copper plate or the like. The optional insulator 1520 is not shown. FIG. 15F is a side cutaway view of the sensor portion 1500E that shows the emitters 1504.

[0255] In the depicted embodiment, the conductive shield 1506 of the cable 1512 is soldered to the heat sink layer 1530 instead of the submount 1502. The solder joint 1565 is shown. In some embodiments, a larger solder joint 1565 can assist with removing heat more rapidly from the emitters 1504. Various connections 1563 between the submount 1502 and a circuit board 1519 are shown. In addition, the cylindrical housing 1580 is shown protruding through the circuit board 1519. The emitters 1504 are enclosed in the cylindrical housing 1580.

[0256] FIGS. 15G and 15H illustrate embodiments of connector features that can be used with any of the sensors described above with respect to FIGS. 1 through 15F. Referring to FIG. 15G, the circuit board 1519 includes a female connector 1575 that mates with a male connector 1577 connected to a daughter board 1587. The daughter board 1587 includes connections to the electrical wiring 1514 of the cable 1512. The connected boards 1519, 1587 are shown in FIG. 15H. Also shown is a hole 1573 that can receive the cylindrical housing 1580 described above.

[0257] Advantageously, in certain embodiments, using a daughter board 1587 to connect to the circuit board 1519 can enable connections to be made more easily to the circuit board 1519. In addition, using separate boards can be easier to manufacture than a single circuit board 1519 with all connections soldered to the circuit board 1519.

[0258] FIG. 15I illustrates an exemplary architecture for front-end interface 108 as a transimpedance-based front-end. As noted, front-end interfaces 108 provide an interface that adapts the output of detectors 106 into a form that can be handled by signal processor 110. As shown in this figure, sensor 101 and front-end interfaces 108 may be integrated together as a single component, such as an integrated circuit.



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Of course, one skilled in the art will recognize that sensor **101** and front end interfaces **108** may comprise multiple components or circuits that are coupled together.

[0259] Front-end interfaces **108** may be implemented using transimpedance amplifiers that are coupled to analog to digital converters in a sigma delta converter. In some embodiments, a programmable gain amplifier (PGA) can be used in combination with the transimpedance-based front-ends. For example, the output of a transimpedance-based front-end may be output to a sigma-delta ADC that comprises a PGA. A PGA may be useful in order to provide another level of amplification and control of the stream of signals from detectors **106**. The PGA may be an integrated circuit or built from a set of micro-relays. Alternatively, the PGA and ADC components in converter **900** may be integrated with the transimpedance-based front-end in sensor **101**.

[0260] Due to the low-noise requirements for measuring blood analytes like glucose and the challenge of using multiple photodiodes in detector **106**, the applicants developed a noise model to assist in configuring front-end **108**. Conventionally, those skilled in the art have focused on optimizing the impedance of the transimpedance amplifiers to minimize noise.

[0261] However, the following noise model was discovered by the applicants:

$$\text{Noise} = \sqrt{aR + bR^2}, \text{ where:}$$

[0262]  $aR$  is characteristic of the impedance of the transimpedance amplifier; and

[0263]  $bR^2$  is characteristic of the impedance of the photodiodes in detector and the number of photodiodes in detector **106**.

[0264] The foregoing noise model was found to be helpful at least in part due to the high SNR required to measure analytes like glucose. However, the foregoing noise model was not previously recognized by artisans at least in part because, in conventional devices, the major contributor to noise was generally believed to originate from the emitter or the LEDs. Therefore, artisans have generally continued to focus on reducing noise at the emitter.

[0265] However, for analytes like glucose, the discovered noise model revealed that one of the major contributors to noise was generated by the photodiodes. In addition, the amount of noise varied based on the number of photodiodes coupled to a transimpedance amplifier. Accordingly, combinations of various photodiodes from different manufacturers, different impedance values with the transimpedance amplifiers, and different numbers of photodiodes were tested as possible embodiments.

[0266] In some embodiments, different combinations of transimpedance to photodiodes may be used. For example, detectors **1-4** (as shown, e.g., in FIG. **12A**) may each comprise four photodiodes. In some embodiments, each detector of four photodiodes may be coupled to one or more transimpedance amplifiers. The configuration of these amplifiers may be set according to the model shown in FIG. **15J**.

[0267] Alternatively, each of the photodiodes may be coupled to its own respective transimpedance amplifier. For example, transimpedance amplifiers may be implemented as integrated circuits on the same circuit board as detectors **1-4**. In this embodiment, the transimpedance amplifiers may be grouped into an averaging (or summing) circuit, which are known to those skilled in the art, in order to provide an output stream from the detector. The use of a summing amplifier to

combine outputs from several transimpedance amplifiers into a single, analog signal may be helpful in improving the SNR relative to what is obtainable from a single transimpedance amplifier. The configuration of the transimpedance amplifiers in this setting may also be set according to the model shown in FIG. **15J**.

[0268] As yet another alternative, as noted above with respect to FIGS. **12E** through **12H**, the photodiodes in detectors **106** may comprise multiple active areas that are grouped together. In some embodiments, each of these active areas may be provided its own respective transimpedance. This form of pairing may allow a transimpedance amplifier to be better matched to the characteristics of its corresponding photodiode or active area of a photodiode.

[0269] As noted, FIG. **15J** illustrates an exemplary noise model that may be useful in configuring transimpedance amplifiers. As shown, for a given number of photodiodes and a desired SNR, an optimal impedance value for a transimpedance amplifier could be determined.

[0270] For example, an exemplary "4 PD per stream" sensor **1502** is shown where detector **106** comprises four photodiodes **1502**. The photodiodes **1502** are coupled to a single transimpedance amplifier **1504** to produce an output stream **1506**. In this example, the transimpedance amplifier comprises  $10\text{ M}\Omega$  resistors **1508** and **1510**. Thus, output stream **1506** is produced from the four photodiodes (PD) **1502**. As shown in the graph of FIG. **15J**, the model indicates that resistance values of about  $10\text{ M}\Omega$  may provide an acceptable SNR for analytes like glucose.

[0271] However, as a comparison, an exemplary "1 PD per stream" sensor **1512** is also shown in FIG. **15J**. In particular, sensor **1512** may comprise a plurality of detectors **106** that each comprises a single photodiode **1514**. In addition, as shown for this example configuration, each of photodiodes **1514** may be coupled to respective transimpedance amplifiers **1516**, e.g., 1 PD per stream. Transimpedance amplifiers are shown having  $40\text{ M}\Omega$  resistors **1518**. As also shown in the graph of FIG. **15J**, the model illustrates that resistance values of  $40\text{ M}\Omega$  for resistors **1518** may serve as an alternative to the 4 photodiode per stream architecture of sensor **1502** described above and yet still provide an equivalent SNR.

[0272] Moreover, the discovered noise model also indicates that utilizing a 1 photodiode per stream architecture like that in sensor **1512** may provide enhanced performance because each of transimpedance amplifiers **1516** can be tuned or optimized to its respective photodiodes **1518**. In some embodiments, an averaging component **1520** may also be used to help cancel or reduce noise across photodiodes **1518**.

[0273] For purposes of illustration, FIG. **15K** shows different architectures (e.g., four PD per stream and one PD per stream) for various embodiments of a sensor and how components of the sensor may be laid out on a circuit board or substrate. For example, sensor **1522** may comprise a "4 PD per stream" architecture on a submount **700** in which each detector **106** comprises four (4) photodiodes **1524**. As shown for sensor **1522**, the output of each set of four photodiodes **1524** is then aggregated into a single transimpedance amplifier **1526** to produce a signal.

[0274] As another example, a sensor **1528** may comprise a "1 PD per stream" architecture on submount **700** in which each detector **106** comprises four (4) photodiodes **1530**. In sensor **1528**, each individual photodiode **1530** is coupled to a

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respective transimpedance amplifier 1532. The output of the amplifiers 1532 may then be aggregated into averaging circuit 1520 to produce a signal.

[0275] As noted previously, one skilled in the art will recognize that the photodiodes and detectors may be arranged in different fashions to optimize the detected light. For example, sensor 1534 illustrates an exemplary “4 PD per stream” sensor in which the detectors 106 comprise photodiodes 1536 arranged in a linear fashion. Likewise, sensor 1538 illustrates an exemplary “1 PD per stream” sensor in which the detectors comprise photodiodes 1540 arranged in a linear fashion.

[0276] Alternatively, sensor 1542 illustrates an exemplary “4 PD per stream” sensor in which the detectors 106 comprise photodiodes 1544 arranged in a two-dimensional pattern, such as a zig-zag pattern. Sensor 1546 illustrates an exemplary “1 PD per stream” sensor in which the detectors comprise photodiodes 1548 also arranged in a zig-zag pattern.

[0277] FIG. 15L illustrates an exemplary architecture for a switched-capacitor-based front-end. As shown, front-end interfaces 108 may be implemented using switched capacitor circuits and any number of front-end interfaces 108 may be implemented. The output of these switched capacitor circuits may then be provided to a digital interface 1000 and signal processor 110. Switched capacitor circuits may be useful in system 100 for their resistor free design and analog averaging properties. In particular, the switched capacitor circuitry provides for analog averaging of the signal that allows for a lower smaller sampling rate (e.g., 2 KHz sampling for analog versus 48 KHz sampling for digital designs) than similar digital designs. In some embodiments, the switched capacitor architecture in front end interfaces 108 may provide a similar or equivalent SNR to other front end designs, such as a sigma delta architecture. In addition, a switched capacitor design in front end interfaces 108 may require less computational power by signal processor 110 to perform the same amount of decimation to obtain the same SNR.

[0278] FIGS. 16A and 16B illustrate embodiments of disposable optical sensors 1600. In an embodiment, any of the features described above, such as protrusion, shielding, and/or heat sink features, can be incorporated into the disposable sensors 1600 shown. For instance, the sensors 1600 can be used as the sensors 101 in the system 100 described above with respect to FIG. 1. Moreover, any of the features described above, such as protrusion, shielding, and/or heat sink features, can be implemented in other disposable sensor designs that are not depicted herein.

[0279] The sensors 1600 include an adult/pediatric sensor 1610 for finger placement and a disposable infant/neonate sensor 1602 configured for toe, foot or hand placement. Each sensor 1600 has a tape end 1610 and an opposite connector end 1620 electrically and mechanically interconnected via a flexible coupling 1630. The tape end 1610 attaches an emitter and detector to a tissue site. Although not shown, the tape end 1610 can also include any of the protrusion, shielding, and/or heat sink features described above. The emitter illuminates the tissue site and the detector generates a sensor signal responsive to the light after tissue absorption, such as absorption by pulsatile arterial blood flow within the tissue site.

[0280] The sensor signal is communicated via the flexible coupling 1630 to the connector end 1620. The connector end 1620 can mate with a cable (not shown) that communicates the sensor signal to a monitor (not shown), such as any of the

cables or monitors shown above with respect to FIGS. 2A through 2D. Alternatively, the connector end 1620 can mate directly with the monitor.

[0281] FIG. 17 illustrates an exploded view of certain of the components of the sensor 301f described above. A heat sink 1751 and a cable 1781 attach to an emitter shell 1704. The emitter shell attaches to a flap housing 1707. The flap housing 1707 includes a receptacle 1709 to receive a cylindrical housing 1480/1580 (not shown) attached to an emitter submount 1702, which is attached to a circuit board 1719.

[0282] A spring 1787 attaches to a detector shell 1706 via pins 1783, 1785, which hold the emitter and detector shells 1704, 1706 together. A support structure 1791 attaches to the detector shell 1706, which provides support for a shielding enclosure 1790. A noise shield 1713 attaches to the shielding enclosure 1790. A detector submount 1700 is disposed inside the shielding enclosure 1790. A finger bed 1710 provides a surface for placement of the patient's finger. Finger bed 1710 may comprise a gripping surface or gripping features, which may assist in placing and stabilizing a patient's finger in the sensor. A partially cylindrical protrusion 1705 may also be disposed in the finger bed 1710. As shown, finger bed 1710 attaches to the noise shield 1703. The noise shield 1703 may be configured to reduce noise, such as from ambient light and electromagnetic noise. For example, the noise shield 1703 may be constructed from materials having an opaque color, such as black or a dark blue, to prevent light piping.

[0283] Noise shield 1703 may also comprise a thermistor 1712. The thermistor 1712 may be helpful in measuring the temperature of a patient's finger. For example, the thermistor 1712 may be useful in detecting when the patient's finger is reaching an unsafe temperature that is too hot or too cold. In addition, the temperature of the patient's finger may be useful in indicating to the sensor the presence of low perfusion as the temperature drops. In addition, the thermistor 1712 may be useful in detecting a shift in the characteristics of the water spectrum in the patient's finger, which can be temperature dependent.

[0284] Moreover, a flex circuit cover 1706 attaches to the pins 1783, 1785. Although not shown, a flex circuit can also be provided that connects the circuit board 1719 with the submount 1700 (or a circuit board to which the submount 1700 is connected). A flex circuit protector 1760 may be provided to provide a barrier or shield to the flex circuit (not shown). In particular, the flex circuit protector 1760 may also prevent any electrostatic discharge to or from the flex circuit. The flex circuit protector 1760 may be constructed from well known materials, such as a plastic or rubber materials.

[0285] FIG. 18 shows the results obtained by an exemplary sensor 101 of the present disclosure that was configured for measuring glucose. This sensor 101 was tested using a pure water ex-vivo sample. In particular, ten samples were prepared that ranged from 0-55 mg/dL. Two samples were used as a training set and eight samples were then used as a test population. As shown, embodiments of the sensor 101 were able to obtain at least a standard deviation of 13 mg/dL in the training set and 11 mg/dL in the test population.

[0286] FIG. 19 shows the results obtained by an exemplary sensor 101 of the present disclosure that was configured for measuring glucose. This sensor 101 was tested using a turbid ex-vivo sample. In particular, 25 samples of water/glucose/Lyposin were prepared that ranged from 0-55 mg/dL. Five samples were used as a training set and 20 samples were then used as a test population. As shown, embodiments of sensor

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**101** were able to obtain at least a standard deviation of 37 mg/dL in the training set and 32 mg/dL in the test population. **[0287]** FIGS. 20 through 22 shows other results that can be obtained by an embodiment of system **100**. In FIG. 20, 150 blood samples from two diabetic adult volunteers were collected over a 10-day period. Invasive measurements were taken with a YSI glucometer to serve as a reference measurement. Noninvasive measurements were then taken with an embodiment of system **100** that comprised four LEDs and four independent detector streams. As shown, the system **100** obtained a correlation of about 85% and Arms of about 31 mg/dL.

**[0288]** In FIG. 21, 34 blood samples were taken from a diabetic adult volunteer collected over a 2-day period. Invasive measurements were also taken with a glucometer for comparison. Noninvasive measurements were then taken with an embodiment of system **100** that comprised four LEDs in emitter **104** and four independent detector streams from detectors **106**. As shown, the system **100** was able to attain a correlation of about 90% and Arms of about 22 mg/dL.

**[0289]** The results shown in FIG. 22 relate to total hemoglobin testing with an exemplary sensor **101** of the present disclosure. In particular, 47 blood samples were collected from nine adult volunteers. Invasive measurements were then taken with a CO-oximeter for comparison. Noninvasive measurements were taken with an embodiment of system **100** that comprised four LEDs in emitter **104** and four independent detector channels from detectors **106**. Measurements were averaged over 1 minute. As shown, the testing resulted in a correlation of about 93% and Arms of about 0.8 mg/dL.

**[0290]** Conditional language used herein, such as, among others, “can,” “could,” “might,” “may,” “e.g.,” and the like, unless specifically stated otherwise, or otherwise understood within the context as used, is generally intended to convey that certain embodiments include, while other embodiments do not include, certain features, elements and/or states. Thus, such conditional language is not generally intended to imply that features, elements and/or states are in any way required for one or more embodiments or that one or more embodiments necessarily include logic for deciding, with or without author input or prompting, whether these features, elements and/or states are included or are to be performed in any particular embodiment.

**[0291]** While certain embodiments of the inventions disclosed herein have been described, these embodiments have been presented by way of example only, and are not intended to limit the scope of the inventions disclosed herein. Indeed, the novel methods and systems described herein can be embodied in a variety of other forms; furthermore, various omissions, substitutions and changes in the form of the methods and systems described herein can be made without departing from the spirit of the inventions disclosed herein. The claims and their equivalents are intended to cover such forms or modifications as would fall within the scope and spirit of certain of the inventions disclosed herein.

What is claimed is:

1. A noninvasive device capable of producing a signal responsive to light attenuated by tissue at a measurement site, the device comprising:

an optical source configured to emit optical radiation at least at wavelengths between about 1600 nm and about 1700 nm; and

a plurality of photodetectors each configured to detect the optical radiation from said optical source after attenua-

tion by said tissue of said measurement site and each output a respective signal stream responsive to said detected optical radiation.

2. The device of claim 1, wherein the optical source is configured to emit optical radiation at wavelengths from about 1600 to about 1670 nm.

3. The device of claim 1, wherein the optical source is configured to emit three wavelengths of optical radiation between about 1600 to about 1700 nm.

4. The device of claim 3, wherein the optical source is configured to emit optical radiation at three wavelengths about 30 nm apart.

5. The device of claim 3, wherein the optical source is configured to emit optical radiation at about 1610 nm, about 1645 nm, and about 1665 nm.

6. The device of claim 1, comprising a patient monitor capable of processing the plurality of output signal streams to determine output values for one or more physiological parameters.

7. The device of claim 6, wherein one of the one or more physiological parameters comprises glucose.

8. A noninvasive, physiological sensor capable of outputting a signal responsive to a blood analyte present in a monitored patient, said sensor comprising:

a sensor housing;

an optical source positioned by said housing with respect to a tissue site of a patient when said housing is applied to the patient; and

photodetectors positioned by said housing with respect to said tissue site when said housing is applied to the patient with a variation in path length among at least some of the photodetectors from the optical source, the photodetectors configured to detect a sequence of optical radiation from said optical source after attenuation by tissue of said tissue site, said photodetectors each configured to output a respective signal stream responsive to said detected sequence of optical radiation and wherein an output signal responsive to one or more of the signal streams is usable to determine the blood analyte based at least in part on the variation in path length.

9. The sensor of claim 8, wherein the blood analyte comprises glucose, wherein the sensor comprises electronic circuitry configured to receive said signals responsive to said detected sequence of optical radiation and wherein said output signal is indicative of said glucose.

10. The sensor of claim 8, comprising a display coupled to the sensor housing and configured to display information indicating the blood analyte.

11. The sensor of claim 6, comprising a signal medium that is configured to connect to a processing device.

12. The sensor of claim 8, further comprising an interface configured to provide the signal to a device external to the sensor.

13. The sensor of claim 12, wherein the interface comprises at least one transimpedance amplifier configured to amplify the signal stream from the photodetectors.

14. The sensor of claim 12, wherein the interface comprises at least one switched capacitor circuit configured to convert said signal stream from the photodetectors into digital information.

15. The sensor of claim 8, wherein the housing comprises a shell constructed of material capable of reflecting at least some of the optical radiation back into the tissue site.

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16. The sensor of claim 6, wherein the optical source comprises at least one set of sources comprising at least one light emitting diode and at least one super-luminescent light emitting diode.

17. The sensor of claim 16, wherein the light emitting diode is configured to transmit optical radiation at a wavelength of approximately 900 to approximately 1300 nm.

18. The sensor of claim 16, wherein the super-luminescent light emitting diode is configured to transmit optical radiation at a wavelength of approximately 1650 to approximately 1800 nm.

19. The sensor of claim 8, wherein the photodetectors are housed within optically separate compartments that reduce mixing of optical radiation from different regions of the tissue site.

20. The sensor of claim 8, further comprising an optical noise reducer capable of reducing ambient light from entering the tissue site.

21. The sensor of claim 8, further comprising a heat sink configured to dissipate heat from the sensor.

22. The sensor of claim 8, wherein the photodetectors are arranged in a special geometry.

23. The sensor of claim 22, wherein the special geometry comprises a substantially linear geometry.

24. The sensor of claim 23, wherein the special substantially linear geometry comprises substantially equal spacing.

25. The sensor of claim 23, wherein the special substantially linear geometry comprises substantially unequal spacing.

26. The sensor of claim 23, wherein the special substantially linear geometry comprises substantially logarithmic spacing.

27. The sensor of claim 23, wherein the special substantially linear geometry comprises substantially progressive spacing.

28. The sensor of claim 22, wherein the special geometry comprises a substantially grid geometry.

29. A method of measuring an analyte based on multiple streams of optical radiation measured from a measurement site, said method comprising:

emitting a sequence of optical radiation pulses to the measurement site;

detecting at a first location a first stream of optical radiation from the measurement site;

detecting at least at one additional location different from the first location an additional stream of optical radiation from the measurement site; and

determining an output measurement value indicative of the analyte based on the detected streams of optical radiation.

30. The method of claim 29, wherein said analyte comprises glucose.

31. The method of claim 29, further comprising converting the detected streams of optical radiation into a digital signal including a respective stream for each location.

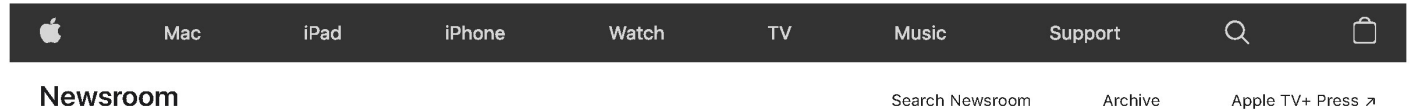
32. The method of claim 29, wherein said emitting comprises emitting light from at least one light emitting diode and at least one super-luminescent light emitting diode.

33. The method of claim 29, wherein said emitting comprises emitting at least one pulse at a wavelength of approximately 900 to approximately 1300 nm.

34. The method of claim 29, wherein said emitting comprises emitting at least one pulse at a wavelength of approximately 1650 to approximately 1800 nm.

\* \* \* \* \*

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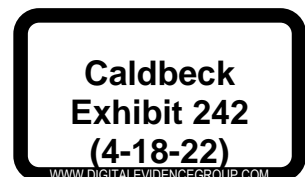
PRESS RELEASE

September 15, 2020

# Apple Watch Series 6 delivers breakthrough wellness and fitness capabilities



Featuring a Blood Oxygen sensor and app, new case finishes, and watchOS 7






Introducing Apple Watch Series 6, featuring a revolutionary Blood Oxygen sensor and app.



Cupertino, California — Apple today announced [Apple Watch Series 6](#), introducing a revolutionary Blood Oxygen feature that offers users even more insight into their overall wellness. Apple Watch Series 6 delivers many notable hardware improvements, including a faster S6 System in Package (SiP) and next-generation always-on altimeter, along with its most colorful lineup yet, featuring a beautiful palette of new case finishes and bands. watchOS 7 brings Family Setup, sleep tracking, automatic handwashing detection, new workout types, and the ability to curate and share watch faces, encouraging customers to be more active, stay connected, and better manage their health in new ways.

“Apple Watch Series 6 completely redefines what a watch can do,” said Jeff Williams, Apple’s chief operating officer. “With powerful new features, including a Blood Oxygen sensor and app,<sup>1</sup> Apple Watch becomes even more indispensable by providing further insight into overall well-being.”



Apple Watch Series 6 offers its most colorful collection yet.



## Blood Oxygen Sensor and App

Apple Watch Series 6 expands the health capabilities of previous Apple Watch models with a new feature that conveniently measures the oxygen saturation of the user's blood, so they can better understand their overall fitness and wellness. Oxygen saturation, or SpO2, represents the percentage of oxygen being carried by red blood cells from the lungs to the rest of the body, and indicates how well this oxygenated blood is being delivered throughout the body.

To compensate for natural variations in the skin and improve accuracy, the Blood Oxygen sensor employs four clusters of green, red, and infrared LEDs, along with the four photodiodes on the back crystal of Apple Watch, to measure light reflected back from blood. Apple Watch then uses an advanced custom algorithm built into the Blood Oxygen app, which is designed to measure blood oxygen between 70 percent and 100 percent. On-demand measurements can be taken while the user is still, and periodic background measurements occur when they are inactive, including during sleep. All data will be visible in the Health app, and the user will be able to track trends over time to see how their blood oxygen level changes.



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The new Blood Oxygen sensor and app conveniently measure the oxygen saturation of blood so users can better understand their overall fitness and wellness.



Apple is joining forces with researchers to conduct three health studies that include using Apple Watch to explore how blood oxygen levels can be used in future health applications. This year, Apple will collaborate with the University of California, Irvine, and Anthem to examine how longitudinal measurements of blood oxygen and other physiological signals can help manage and control asthma.

Separately, Apple will work closely with investigators at the Ted Rogers Centre for Heart Research and the Peter Munk Cardiac Centre at the University Health Network, one of the largest health research organizations in North America, to better understand how blood oxygen measurements and other Apple Watch metrics can help with management of heart failure. Finally, investigators with the Seattle Flu Study at the Brotman Baty Institute for Precision Medicine and faculty from the University of Washington School of Medicine will seek to learn how signals from apps on Apple Watch, such as Heart Rate and Blood Oxygen, could serve as early signs of respiratory conditions like influenza and COVID-19.



The Blood Oxygen sensor employs LEDs, along with photodiodes on the back crystal of Apple Watch Series 6.



## Design and Performance

Apple Watch Series 6 improves performance through redesigned hardware that packs even more features and power into the same impressively small design. Using a new dual-core processor based on A13 Bionic in iPhone 11, the upgraded S6 SiP runs up to 20 percent faster, allowing apps to also launch 20 percent faster, while maintaining the same all-day 18-hour battery life.<sup>2</sup> Additionally, Apple Watch Series 6 features the U1 chip and Ultra Wideband antennas,<sup>3</sup> which will enable short-range wireless location to support new experiences, such as next-generation digital car keys. Apple Watch Series 6 offers faster charging, completing a full charge in under 1.5 hours, and improved battery life for tracking certain workouts, such as indoor and outdoor runs.

An enhanced Always-On Retina display on Apple Watch Series 6 is up to 2.5 times brighter than Apple Watch Series 5 outdoors when the user's wrist is down, making it much easier to see a watch face in bright sunlight. When their wrist is down, the user can also now access Notification Center and Control Center, tap on complications, and swipe to change faces without having to wake their watch screen.



The Always-On Retina display is 2.5 times brighter while the user's wrist is down.



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## Always-On Altimeter

The always-on altimeter provides real-time elevation all day long by using a new, more power-efficient barometric altimeter, along with GPS and nearby Wi-Fi networks. This feature allows for the detection of small elevation changes above ground level, up and down to the measurement of 1 foot, and can be shown as a new watch face complication or workout metric.



The always-on altimeter on Apple Watch Series 6 provides real-time elevation all day long.



## Apple Watch Collection

This fall, customers have more choices than ever with stunning new cases and bands to suit every style preference. For the first time, a new blue color joins the silver, space gray, and gold aluminum case options, along with a (PRODUCT)RED Apple Watch with exclusive matching bright red bands. Stainless steel models are now available in graphite — a rich gray-black hue with a striking high-shine finish — and an updated classic yellow gold color. Apple Watch Edition is available in natural and space black titanium.

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Apple Watch Series 6 with the distinct Braided Solo Loop and blue aluminum case.



Three all-new band styles offer customers innovative options that provide a tailored and comfortable fit without traditional clasps or buckles. In an industry first, the ultralight Solo Loop introduces a continuous and stretchable band design that comes in two materials: soft silicone and braided yarn. A special UV treatment process used on the soft silicone of the Solo Loop creates a smooth, silky finish, while a precision-braiding machine interweaves the 16,000 polyester yarn filaments, made of 100 percent recycled material, with ultrathin silicone threads, giving unique stretchability and a distinct look to the Braided Solo Loop. To ensure the best fit, a new sizing system offers nine available lengths for the Solo Loop styles. The first-of-its-kind Leather Link wraps elegantly around the wrist, effortlessly attaching on the other side with flexible molded magnets.

Apple Watch Series 6 delivers breakthrough wellness and fitness capabilities – Apple



Apple Watch Nike now comes with new colors for the Nike Sport Band and Nike Sport Loop.



Apple Watch Nike now comes with new colors for the Nike Sport Band and Nike Sport Loop, and a new Nike Compact watch face allows for multiple Nike Run Club complications. Apple Watch Hermès offers stainless steel cases in silver or space black paired with Single or Double Tour styles in an assortment of vibrant new colors. The fall collection also unveils the Hermès Attelage Single Tour and slimmer Attelage Double Tour bands, which feature a refined connection to the case that reflects the brand's equestrian heritage, and a new Hermès Circulaire watch face that offers increased options for complications.





Apple Watch Hermès introduces the Hermès Attelage Single Tour and slimmer Attelage Double Tour bands, along with new colors of classic band styles.



## watchOS 7

With watchOS 7, customers can take personalization to the next level with seven new watch face options, including Stripes, Chronograph Pro, GMT, and Artist, while curating, discovering, and sharing new watch face configurations with others. New health and fitness features, including low-range VO2 Max, sleep tracking, automatic

handwashing detection, and new workout types, can help users better understand overall well-being. Conveniently accessible on the wrist, Maps includes cycling directions and Siri offers language translation.



watchOS 7 features seven new watch face options — including Chronograph Pro and GMT — plus new watch face configurations users can curate, discover, and share with others.



## Family Setup and Optimized Features for the Entire Family

Family Setup<sup>4</sup> in watchOS 7 extends Apple Watch to the entire family by allowing kids and older family members of the household who do not have an iPhone to benefit from the connectivity, safety, and fitness features of Apple Watch. Kids can take advantage of communication and personalization capabilities, access Emergency SOS at any time, enjoy an Activity rings experience that has been optimized just for them, and utilize a new mode called Schooltime, which can help them stay focused and attentive while learning at home or in the classroom.

watchOS 7 also offers optimized features for older adults, starting with a simplified onboarding and configuration process, along with a refreshed X-Large face that shows the time and a rich complication at a glance. Older adults can also benefit

from a new Health Checklist in the Health app on iPhone, which offers the ability to track whether health features like fall detection have been enabled in one centralized view.

#### Pricing and Availability

- Apple Watch Series 6 (GPS) starts at **\$399** and Apple Watch Series 6 (GPS + Cellular) starts at **\$499**.
- Apple Watch Series 6 (GPS) is available to order today from [apple.com](https://apple.com) and in the Apple Store app, with availability beginning Friday, September 18, in the *US, Puerto Rico*, and 27 other countries and regions.
- Apple Watch Series 6 (GPS + Cellular) is available to order today from [apple.com](https://apple.com) and in the Apple Store app, with availability beginning Friday, September 18, in the *US, Puerto Rico*, and 21 other countries and regions. For carrier availability, visit [apple.com/watch/cellular](https://apple.com/watch/cellular).
- Apple Watch Nike is available to order today from [apple.com](https://apple.com) and in the Apple Store app, with availability beginning Friday, September 18, in the *US, Puerto Rico*, and more than 27 other countries and regions. For more information, visit [apple.com/apple-watch-nike](https://apple.com/apple-watch-nike) or [nike.com/applewatch](https://nike.com/applewatch).
- Apple Watch Hermès is available to order today from [apple.com](https://apple.com) and in the Apple Store app, with availability beginning Friday, September 18, in the *US* and more than 14 other countries and regions. For more information, visit [apple.com/apple-watch-hermes](https://apple.com/apple-watch-hermes) or [hermes.com/applewatchhermes](https://hermes.com/applewatchhermes).
- New Apple Watch bands are available to order today from [apple.com](https://apple.com) and in the Apple Store app, with availability beginning Friday, September 18. Solo Loop and Braided Solo Loop in (PRODUCT)RED will be available in late October. Solo Loop and Braided Solo Loop are compatible with Apple Watch Series 4 and later.
- watchOS 7 will be available for Apple Watch Series 3 and later on September 16, and requires iPhone 6s or later running iOS 14. Not all features are available on all devices.
- When customers buy directly from Apple, Apple Watch Studio gives them the exclusive opportunity to pick their preferred case and band combination to create a look that is uniquely their own.
- Customers looking for convenient, contactless service are able to find many of the same shopping and support services from [apple.com](https://apple.com). Customers can chat with an Apple Specialist and get shopping help, choose monthly financing options, trade in eligible devices, and get Genius support and no-contact delivery. In-store pickup is also available. Customers are encouraged to check [apple.com/retail](https://apple.com/retail) for more information on the health and safety measures in place, and the services available at their local store.
- Customers in the US can trade in their eligible device for an Apple Gift Card or credit toward their purchase. If the device is not eligible for credit, Apple will recycle it for free.<sup>5</sup>
- Three months of Apple Fitness+ are included for customers who purchase Apple Watch Series 3 or later starting September 15, 2020. This extended trial is available for a limited time.<sup>6</sup>
- Customers in the US who buy directly from Apple can choose Apple Card Monthly installments to pay for their Apple Watch over 24 months, interest-free, and get 3 percent Daily Cash back all upfront. Customers who choose to pay in full with their Apple Card also get 3 percent Daily Cash back.
- Customers can extend their limited warranty with AppleCare+ and get accidental damage coverage and 24/7 priority access to technical support.



- Customers who buy Apple Watch directly from Apple can enjoy a free Online Personal Session with an Apple Specialist to help them explore and discover all the amazing things they can do with their new Apple Watch.<sup>7</sup>
- In line with Apple's commitment to the environment, there are industry-leading amounts of recycled content in Apple Watch Series 6, with 100 percent recycled rare earth elements in the Taptic Engine, nearly 100 percent recycled tungsten throughout the product, and a 100 percent recycled case on aluminum models. Apple is also helping the environment by removing the AC adapter that could become electronic waste from Apple Watch Series 6 packaging, and helping its Apple Watch manufacturing partners transition to renewable energy.

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To see all of the latest announcements and photos from today's keynote event, check out the [wrap-up on Apple Newsroom](#).

## Share article



Images of Apple Watch Series 6

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Apple revolutionized personal technology with the introduction of the Macintosh in 1984. Today, Apple leads the world in innovation with iPhone, iPad, Mac, Apple Watch, and Apple TV. Apple's five software platforms — iOS, iPadOS, macOS, watchOS, and tvOS — provide seamless experiences across all Apple devices and empower people with breakthrough services including the App Store, Apple Music, Apple Pay, and iCloud. Apple's more than 100,000 employees are dedicated to making the best products on earth, and to leaving the world better than we found it.

1. Blood Oxygen app measurements are not intended for medical use, including self-diagnosis or consultation with a doctor, and are only designed for general fitness and wellness purposes.
2. Battery life varies by use.
3. Not available in all countries.
4. Requires cellular models of Apple Watch Series 4 or later, or Apple Watch SE.
5. Trade-in values vary based on the condition, year, and configuration of your trade-in device, and may also vary between online and in-store trade-in. You must be at least 18 years old. Offer may not be available in all countries. In-store trade-in requires presentation of a valid government-issued photo ID (local law may require saving this information). Additional terms from Apple or Apple's trade-in partners may apply.
6. \$9.99 per month or \$79.99 per year after free trial. No commitment. Plan automatically renews until cancelled.
7. In most countries.

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